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CRAWFORDSVILLE (INDIANA) CRINOID STUDIES

By JAN F. VAN SANT and N. GARY LANE



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TABLES

TABLE	PAGE		PAGE
1. Numbers of Crawfordsville crinoid species described in various periods	9	21. Measurements of <i>Histocrinus coreyi</i>	93
2. Terminology employed for types of articulations	37	22. Measurements of <i>Histocrinus graphicus</i>	94
3. Articulations between ossicles of <i>Taxocrinus colletti</i>	45	23. Measurements of <i>Hypselocrinus hoveyi</i>	95
4. Measurement of <i>Eucatillocrinus bradleyi</i>	69	24. Measurements of <i>Hypselocrinus indianaensis</i> ..	96
5. Measurements of <i>Synbathocrinus swallowi</i>	72	25. Measurements of <i>Scytalocrinus disparilis</i>	97
6. Measurements of <i>Parisocrinus crawfordsvillensis</i>	73	26. Measurements of <i>Scytalocrinus robustus</i>	98
7. Measurements of <i>Barycrinus asteriscus</i>	74	27. Measurements of <i>Onychocrinus exculptus</i>	101
8. Measurements of <i>Barycrinus hoveyi</i>	76	28. Measurements of <i>Onychocrinus ramulosus</i>	102
9. Measurements of <i>Barycrinus? neglectus</i>	77	29. Measurements of <i>Taxocrinus colletti</i>	103
10. Measurements of <i>Barycrinus princeps</i>	77	30. Measurements of <i>Gilbertocrinus tuberosus</i>	106
11. Measurements of <i>Pellecrinus hexadactylus</i>	78	31. Comparison of batocrinid genera recognized prior to 1958 with those recognized by LANE ..	107
12. Measurements of <i>Cyathocrinites multibrachiatatus</i>	82	32. Measurements of <i>Abatocrinus grandis</i>	109
13. Measurements of <i>Cyathocrinites opimus</i>	82	33. Measurements of <i>Alloprosallocrinus conicus</i>	111
14. Measurements of <i>Cyathocrinites poterium</i>	82	34. Measurements of <i>Dizygocrinus crawfordsvillensis</i>	112
15. Measurements of <i>Abrotocrinus coreyi</i>	85	35. Measurements of <i>Dizygocrinus indianaensis</i> ..	114
16. Measurements of <i>Abrotocrinus unicus</i>	86	36. Measurements of <i>Dizygocrinus montgomeryensis</i>	115
17. Measurements of <i>Pachylocrinus aequalis</i>	88	37. Measurements of <i>Macrocrinus mundulus</i>	117
18. Measurements of <i>Pachylocrinus gibsoni</i>	89	38. Measurements of <i>Agariocrinus splendens</i>	120
19. Characteristic features of scytalocrinid genera found at Crawfordsville	91	39. Measurements of <i>Dichocrinus ficus</i>	121
20. Measurements of <i>Decadocrinus depressus</i>	92	40. Measurements of <i>Campocrinus crawfordsvillensis</i>	124
		41. Measurements of <i>Paradichocrinus polydactytus</i> ..	125
		42. Measurements of <i>Platycrinites hemisphericus</i> ..	126

CRAWFORDSVILLE (INDIANA) CRINOID STUDIES

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CONTENTS

	PAGE		PAGE
PREFACE (Raymond C. Moore)	5	<i>Barycrinus? neglectus</i>	76
ABSTRACT (Jan F. Van Sant & N. Gary Lane)	6	<i>Barycrinus princeps</i>	77
SETTING OF CRAWFORDSVILLE CRINOID STUDIES (Jan		<i>Pellecrinus hexadactylus</i>	78
F. Van Sant & N. Gary Lane)	6	<i>Cyathocrinites benedicti</i>	79
Purpose and scope of investigation	6	? <i>Cyathocrinites insperatus</i>	79
Material and collections	7	<i>Cyathocrinites multibrachiatus</i>	80
Designation of specimens	7	<i>Cyathocrinites opimus</i>	81
Location of area	8	<i>Cyathocrinites poterium</i>	82
Previous studies	8	<i>Lebetocrinus grandis</i>	83
Exploitation of crinoid beds	10	<i>Graphiocrinus mcadamsi</i>	83
Discoverers—1842-58	10	<i>Cydrocrinus concinnus</i>	83
Free-for-all—1858-75	11	<i>Abrotocrinus coreyi</i>	85
No trespassing—1875-96	14	<i>Abrotocrinus unicus</i>	85
End of an era—1896-1906	20	<i>Pachylocrinus aequalis</i>	87
CRAWFORDSVILLE CRINOID BEDS (N. Gary Lane &		<i>Pachylocrinus gibsoni</i>	89
Jan F. Van Sant)	22	<i>Pachylocrinus manus</i>	89
Early stratigraphic interpretations	22	<i>Springericrinus magniventrus</i>	90
Upper Borden Group in Montgomery County,		<i>Decadocrinus depressus</i>	91
Indiana	24	<i>Decadocrinus tumidulus</i>	92
General description	24	<i>Histocrinus coreyi</i>	93
Facies changes	28	<i>Histocrinus graphicus</i>	94
Lithology of crinoid-bearing beds	30	<i>Hypselocrinus hoveyi</i>	95
Composition and age of Crawfordsville crinoid		<i>Hypselocrinus indianensis</i>	95
fauna	30	<i>Scytalocrinus disparilis</i>	96
Paleoecology	33	<i>Scytalocrinus robustus</i>	97
CRAWFORDSVILLE CRINOIDS (Jan F. Van Sant)	34	<i>Sarocrinus granilineus</i>	98
Introduction	34	<i>Corythocrinus fragilis</i>	99
Morphological features	34	<i>Corythocrinus gracilis</i>	99
Articulation of crinoid ossicles	34	<i>Goniocrinus harrisi</i>	99
General discussion	34	Flexible crinoids	100
Observations based on post-Paleozoic forms ..	36	<i>Onychocrinus exculptus</i>	100
Observations based on Paleozoic forms	40	<i>Onychocrinus ramulosus</i>	101
Flexibilia	41	<i>Parichthyocrinus? crawfordsvillensis</i>	102
Camerata	52	<i>Taxocrinus colletti</i>	103
Inadunata	62	Camerate crinoids	104
General remarks	66	<i>Gilbertsocrinus tuberosus</i>	105
Systematic descriptions	67	<i>Actinocrinites gibsoni</i>	106
Introductory statement	67	<i>Abatocrinus grandis</i>	108
Inadunate crinoids	68	<i>Alloprosallocrinus conicus</i>	110
<i>Eucatillocrinus bradleyi</i>	68	<i>Dizygocrinus crawfordsvillensis</i>	111
<i>Halysiocrinus bradleyi</i>	69	<i>Dizygocrinus indianensis</i>	112
<i>Synbathocrinus swallovi</i>	71	<i>Dizygocrinus montgomeryensis</i>	114
<i>Parisocrinus crawfordsvillensis</i>	72	<i>Eretmocrinus commendabilis</i>	116
<i>Barycrinus asteriscus</i>	73	<i>Macrocrinus mundulus</i>	117
<i>Barycrinus hoveyi</i>	74	<i>Uperocrinus marinus</i>	118
		<i>Agaricocrinus americanus</i>	118

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	PAGE		PAGE
<i>Agaricocrinus splendens</i>	119	<i>Paradichocrinus polydactylus</i>	124
<i>Dichocrinus ficus</i>	121	<i>Platycrinites hemisphericus</i>	125
<i>Dichocrinus recurvibrachiatus</i>	121	APPENDIX A, Terminology and abbreviations used ..	126
<i>Dichocrinus</i> sp.	122	APPENDIX B, Check-list of names applied to Craw-	
<i>Camptocrinus crawfordsvillensis</i>	123	fordsville crinoids	127
		REFERENCES	130

ILLUSTRATIONS

PLATES	FACING PAGE		FACING PAGE
1. Crawfordsville crinoids: <i>Eucatillocrinus</i> , <i>Barycrinus</i> , <i>Synbathocrinus</i> , <i>Parisocrinus</i> , <i>Pellecrinus</i>	80	6. Crawfordsville crinoids: <i>Taxocrinus</i> , <i>Onychocrinus</i>	113
2. Crawfordsville crinoids: <i>Cyathocrinites</i> , <i>Barycrinus</i> , <i>Pellecrinus</i>	81	7. Crawfordsville crinoids: <i>Dichocrinus</i> , <i>Alloprosalloccrinus</i> , <i>Abatocrinus</i> , <i>Dizygocrinus</i> , <i>Onychocrinus</i> , <i>Eretmocrinus</i>	128
3. Crawfordsville crinoids: <i>Abrotocrinus</i> , <i>Graphiocrinus</i> , <i>Cyathocrinites</i> , <i>Cydrocrinus</i>	96	8. Crawfordsville crinoids: <i>Agaricocrinus</i> , <i>Uperocrinus</i> , <i>Dizygocrinus</i> , <i>Macrocrinus</i> , <i>Paradichocrinus</i> , <i>Platycrinites</i> , <i>Gilbertsocrinus</i> , <i>Dichocrinus</i>	129
4. Crawfordsville crinoids: <i>Pachylocrinus</i> , <i>Decadocrinus</i> , <i>Histocrinus</i> , <i>Springericrinus</i>	97		
5. Crawfordsville crinoids: <i>Sarocrinus</i> , <i>Histocrinus</i> , <i>Hypselocrinus</i> , <i>Scytalocrinus</i>			112
			113
			128
			129

FIGURES	PAGE		PAGE
1. Location of Montgomery County and Crawfordsville, Indiana	8	23. Advanced types of articular surfaces on certain inadunate ossicles	65
2. Topographic map of part of Montgomery County, Indiana	13	24. Relationships of plates of <i>Eucatillocrinus</i> and <i>Catillocrinus</i>	68
3. Tracts of land near Crawfordsville purchased for excavation of crinoids	19	25. Camera lucida drawings of <i>Halysiocrinus bradleyi</i>	70
4. Edmund O. Hovey, 1801-1877	(facing) 20	26. Camera lucida drawings of <i>Synbathocrinus swallovi</i>	71
5. Horace C. Hovey, 1833-1914	(facing) 20	27. Camera lucida drawing of <i>Parisocrinus crawfordsvillensis</i>	72
6. Frank Springer, 1848-1927	(facing) 20	28. Variation of plates in CD-interray of <i>Barycrinus hoveyi</i>	73
7. Braun quarry near Crawfordsville, Indiana, summer of 1906	(facing) 21	29. Nature of arm branching of <i>Barycrinus asteriscus</i>	74
8. Crinoid localities in Borden Group rocks near Crawfordsville, Indiana	25	30. Patterns of arm branching in <i>Barycrinus hoveyi</i>	75
9. Structures and types of articular surfaces of Recent crinoids	38	31. Patterns of arm branching in <i>Cydrocrinus</i>	84
10. Plates of <i>Forbesiocrinus</i>	42	32. Patterns of arm branching in <i>Abrotocrinus unicus</i>	86
11. "Patelloid structures" developed on some flexible crinoids	43	33. Variation of arm branching on specimens of <i>Pachylocrinus aequalis</i>	87
12. Radials and primibrachs of <i>Forbesiocrinus</i> and <i>Taxocrinus</i>	46	34. Arm branching on three different species of <i>Onychocrinus</i>	101
13. Articular surfaces on selected ossicles of <i>Taxocrinus colletti</i>	47	35. Crown of <i>Gilbertsocrinus tuberosus</i> showing relationship of various structures	104
14. Articular surfaces on selected ossicles of <i>Onychocrinus exculptus</i>	50	36. Proximal portion of paired arms of <i>Abatocrinus grandis</i> ; typical and atypical arrangements	108
15. Portion of arm of <i>Onychocrinus</i> showing relationships of structures	51	37. Dorsal view of <i>Alloprosalloccrinus conicus</i> showing typical and atypical development of primibrachs	110
16. Union of plates of <i>Scyphocrinites</i>	53	38. Variation in arrangement of fixed-brachials in <i>Dizygocrinus indianaensis</i>	114
17. Arm-bearing articular facets of selected camerates from Crawfordsville	55	39. Variation in number of arms arising from a single ambulacral opening on <i>Dizygocrinus indianaensis</i>	115
18. Part of crown of <i>Alloprosalloccrinus conicus</i> with portion of arm facet removed to show relationships of plates	56	40. Variation of anal plates on <i>Dizygocrinus indianaensis</i>	115
19. Articular surfaces on brachials of camerates	58	41. Diagrams of specimens of <i>Camptocrinus</i> species found at Crawfordsville	123
20. Brachial articulations for attachment of pinules	59		
21. Articular surfaces on selected ossicles of several cyathocrinoid inadunates	63		
22. Camera lucida drawing of ventral surface of arms of <i>Barycrinus hoveyi</i>	64		

PREFACE

By RAYMOND C. MOORE

The following contribution by VAN SANT & LANE is an outgrowth, direct in the case of VAN SANT and indirect as regards the work of LANE, of doctoral studies pursued at the University of Kansas under my guidance.

N. GARY LANE received undergraduate training in geology at Oberlin College, Oberlin, Ohio (A.B., 1952). He began graduate studies in geology and paleontology at the University of Kansas in 1952, obtaining his M.S. degree there in 1954. He was a teaching assistant in the Department of Geology, University of Kansas, in 1952-54 and held the Shell Oil Company fellowship at Kansas in 1954-55. The school year of 1955-56 was spent as a Fulbright student at the University of Tasmania, following which he returned to Lawrence for completion of Ph.D. requirements. He obtained this degree from the University of Kansas in 1958, with a thesis on the Mississippian crinoid family Batocrinidae. During summers he worked as field geologist for the Geological Survey of Canada and State Geological Survey of Kansas. LANE was appointed Assistant Professor of Geology at the University of California in Los Angeles in 1958 and has continued teaching and research work there to date. With advanced students he has been active especially in investigations of Pennsylvanian stratigraphy and paleontology in southern Nevada.

Work by LANE on Crawfordsville crinoids began when he discovered that a fairly large collection of these fossils was held by the Museum of Paleontology at the University of California in Berkeley. Virtually no work had been done on it and LANE readily obtained permission to study these fossils. A description of the collection now has been published (LANE, 1963b). A research grant from the University of California in Los Angeles enabled LANE to spend summer months of 1963 in the Crawfordsville area of Indiana with the objectives of learning details about the local occurrence and stratigraphic relations of the crinoid-bearing beds. A plan to renew explorations after more than a half-century of complete inactivity—last excavations being those of BRAUN in 1906—is being shaped to obtain what should be extremely valuable information on paleoecological aspects of the crinoid occurrences and conditions which led to the making of these accumulations. Even

though the Crawfordsville crinoids are famous for the completeness of innumerable individuals, with almost perfectly preserved crowns attached to the columns of varying length which bore them, comparatively little attention has been directed to questions of how these animals lived and how they became buried together in successive layers. It is hoped that field investigations of this sort, never made previously, may be supported by the National Science Foundation.

JAN F. VAN SANT comes from Wisconsin and he obtained the B.S. degree in geology from the University of Wisconsin in 1954. Following two years of military service (1954-56), he entered the Graduate School of the University of Kansas in the Fall of 1956 and received the M.S. degree in geology in 1958. Working as an assistant instructor and research assistant for me, doctoral studies began to be made, at my suggestion, on features of crinoid morphology which might be learned from dissection of Crawfordsville specimens representing the different subclasses and as many genera as possible. An investigation of this nature seemed desirable because of the observed wide range of morphological characters shown by disarticulated crinoid fragments in collections of mine from Ordovician-to-Permian sources and because a Mississippian crinoid assemblage identified as to genera and species had not been examined in manner which might reveal important characters of individual parts. VAN SANT's doctoral thesis was entitled "Crawfordsville Crinoid Fauna of Indiana." In addition to presenting results of comprehensive work on the morphology of individual parts of crinoid skeletons, the thesis contained a review of the history of crinoid exploration in the Crawfordsville area written after study of published records and visits to Crawfordsville and to the Springer library in Washington, D.C. Also, the taxonomy of the assemblage was surveyed, with effort to discriminate between all species validly reported to occur at Crawfordsville and those erroneously recorded as constituents of the assemblage. Main results of these investigations are included in the third part of the present contribution under the heading "Crawfordsville Crinoids."

VAN SANT received his Ph.D. degree from the University of Kansas in 1963, several months after the date of beginning work as research geologist on the staff of the Jersey Production Research Company in

Tulsa, Oklahoma. Projects assigned to him have been entirely in the field of invertebrate paleontology, mostly concerned with groups other than crinoids and with emphasis on paleoecological and stratigraphic relationships. Recently he was chosen to establish

and administer a new paleontological laboratory needed for guidance of exploratory operations of Standard Oil Company of New Jersey affiliates in Europe. The laboratory is being set up in Bordeaux, France.

ABSTRACT

Second to Burlington, Iowa, the most famous crinoid locality in North America is Crawfordsville, Indiana. More than 90 per cent of the 83 previously described crinoid species from this locality were described before 1900, although commonly these were based on a single specimen or at most only a few. Restudy of the fauna has resulted in major reduction in the number of valid species. The numerous specimens available for some species has provided valuable information on morphological characters that are variable, and thus of little taxonomic importance. Fifty-five valid species are recognized, of which only two are new. Twenty-eight previously recognized forms are considered synonyms or their occurrence in the Crawfordsville beds could not be confirmed from published descriptions and material available for study. In addition, several valid species are reallocated to different genera. Considerable effort has been made to clear up nomenclatural confusion of a host of species, including some type species of well-known genera.

A Keokuk age for the fauna is indicated by occurrence of eight species common to rocks in the Crawfordsville area and in undisputed rocks of the same age in the Upper Mississippi Valley, and in Kentucky and Tennessee. Mostly the species found in the Crawfordsville crinoid beds show culminations of evolutionary trends that began in Burlington forms and they differ markedly from known Upper Mississippian species.

The vast majority of the "Crawfordsville crinoids" were collected from an area about 100 yards long, on the side of a bluff on the north bank of Sugar Creek, about one mile north of Crawfordsville. Although a few specimens probably were obtained at other localities in the central part of Montgomery County, these were never catalogued separately and cannot now be identified as

coming from other localities. The crinoids occur in local concentrations or "pockets," but it is impossible to determine if they were imbedded in rock representing a single "pocket" or several. Both allochthonous and autochthonous hypotheses have been proposed to explain the crinoid occurrences; however, preservation of delicate crinoid structures, occurrence of well-preserved fragile bryozoan and sponge remains, and others suggest that an autochthonous occurrence is more logical.

Opportunity to disarticulate selected Crawfordsville specimens has yielded new information on basic crinoid morphology. Flexible crinoids have highly modified ligamentary articulation that are unknown in inadunates, although present in some specialized camerates. Generally, these can be divided into six major types of unions. In camerates the dorsal-cup plates, and commonly brachial plates, are united by close unions that afforded little or no movement; however, the arm-bearing facets and surfaces for attachment of pinnules have somewhat complex structures that permitted relatively much greater movement. In many forms the main function of the rather rigid brachials seems to have been for support of movable pinnules, which served as the main food-gathering organs. Atypical camerates in which the free arms are supported directly by the radials have ligamentary unions similar to those of many inadunates. Representatives of this latter group exhibit both simple and complex ligamentary and true muscular modes of union.

From studies completed thus far it is impossible to evaluate the true significance of unions between plates as they relate to problems of taxonomy. Seemingly, within a given species, the general nature of the surfaces are distinct, but considerable variation occurs in the size, shape, and detailed patterns of structures within the articular surfaces.

SETTING OF CRAWFORDSVILLE CRINOID STUDIES

By J. F. VAN SANT and N. GARY LANE

PURPOSE AND SCOPE OF INVESTIGATION

The purpose of this study is fourfold: (1) to bring together in one study a taxonomic, stratigraphic, and historical review of the famous Mississippian crinoid fauna from Crawfordsville, Indiana; (2) to illustrate photographically many genera and species of crinoids that heretofore have been known only from poorly constructed line drawings; (3) to study various crinoid species that are represented by abundant specimens in an effort to determine variable features needing careful observation for definition of species and higher taxa of crinoids; and (4) study of little-known morphological structures found between various types of crinoid ossicles.

The Crawfordsville beds have yielded one of the best preserved and most abundant faunas known. The

region was extensively exploited during the latter part of the 19th century, collections going to many museums and universities in the United States and Europe. Following initial discovery, the crinoids were collected sporadically by local residents, but with increased demand for these crinoids many professional collectors came to the region. Practically all species described were sold or given to paleontologists by collectors, and subsequent descriptions of species were based on only a few specimens or a single one. The typological approach to the species concept is well known in paleontology, but comparatively few published investigations have been made that re-examine a fauna using concepts now generally considered more reliable and correct. The present study, using abundant specimens of most species,

indicates that many characters that were previously judged important in description of crinoids are highly variable. Thus re-allocation and description of many forms has resulted.

Crawfordsville crinoid species have been described during a period of nearly 100 years, descriptions appearing in numerous publications, some of which are now hard to obtain. Judging from material available for this study, most catalogued Crawfordsville specimens bear out-of-date names, and not uncommonly specimens representing a single species are labelled with two or three names. Thus it is hoped that this study will help various museums to "clean house" and properly organize their catalogued and uncatalogued specimens.

Approximately 500 uncatalogued specimens were loaned by the Walker Museum (University of Chicago) and permission was granted to disassociate the plates artificially in an effort to study basic morphological features of Paleozoic crinoids. This unusual opportunity permitted considerable stress on study of the mode of union between crinoid ossicles, and enough information was gathered to warrant an independent section in the present report. Other morphological features that are discussed could not be similarly organized into an independent section, and thus are discussed in appropriate parts of the systematic paleontology section of this paper.

In an investigation of such a rich fauna as was found at Crawfordsville, examination of all known specimens is impossible. Nearly 3,000 well-preserved specimens were assembled for study but these do not represent half of the specimens known to have been collected. Thus, systematic study of other large collections will undoubtedly result in further revisions.

ACKNOWLEDGMENTS

We are especially grateful for assistance given by Dr. R. C. MOORE, who was responsible for initiating this study and has given much of his time to following closely all phases of our investigations. Special thanks must also be given to Dr. J. MARVIN WELLER (University of Chicago) for permission to disarticulate selected uncatalogued specimens. Drs. R. H. BENSON (Department of Geology) and KENNETH ARMITAGE (Department of Zoology), of the University of Kansas, offered valuable suggestions for major portions of this study. ROGER B. WILLIAMS, a fellow student and staff illustrator for the *Treatise on Invertebrate Paleontology* spent considerable time teaching the senior author methods for preparation of illustrations, and at times was called upon to do more than advise him in order to produce (or save) a satisfactory drawing.

For help in obtaining specimens and information concerning Crawfordsville crinoids we are indebted to the following: Dr. N. D. NEWELL (American Museum of Natural History); Drs. J. M. WELLER and M. H. NITECKI (University of Chicago, Walker Museum); Dr. W. F. JENKS and Mr. G. T. FARMER (University of Cincinnati); Dr. C. L. BIEBER (DePauw University); Drs. C. W. COLLINSON and L. B. KENT (Illinois Geological Survey); Dr. D. B. HATTIN (University of Indiana); Mr. H. L. STRIMPLE (State University of Iowa); Dr. R. V. KESLING (University of Michigan); Dr. H. B. WHITTINGTON (Museum of Comparative Zoology); Dr. D. W. FISHER and Mr. C. F. KILFOYLE (New York State Museum); Drs.

K. M. WAAGE and A. L. MCALESTER (Peabody Museum); Drs. G. A. COOPER and P. M. KIER (U.S. National Museum); Drs. E. C. WILLIAMS, JR. and T. G. GRONERT (Wabash College); Dr. ROBERT H. SHAVER (Indiana Geological Survey); the staffs of the Wabash College and Crawfordsville Public libraries.

Expenses for field study and historical research in Montgomery County by the junior author during the summer of 1963 were subsidized by the Research Committee of the Academic Senate, University of California, Los Angeles.

MATERIAL AND COLLECTIONS

The majority of the specimens used in this study came from the Faber, Gurley, Hall, Miller, and Sampson collections at the Walker Museum (University of Chicago), the Bassett and Bradley collections at Peabody Museum (Yale University), and specimens from New York State Museum (Albany). In addition, several hundred catalogued specimens were loaned by the Illinois Geological Survey and Department of Geology (University of Illinois, Urbana), the Paleontological Museum (University of Cincinnati), and Wabash College (Crawfordsville, Indiana).

A large collection of plastotypes, prepared by R. C. MOORE and now in the Paleontological Museum at the University of Kansas, were available for study. This collection was prepared principally from type specimens in the Springer collection at the U.S. National Museum in Washington and at the American Museum of Natural History in New York and are particularly useful because under conditions stipulated in SPRINGER's will, none of his extensive crinoid collections at the U.S. National Museum can be loaned.

Numerous other institutions have extensive collections of Crawfordsville crinoids, but they were not studied. The Wachsmuth and Dyer collections at the Harvard Museum of Comparative Zoology have nearly 1,000 specimens and the Yale Peabody Museum has nearly 1,500 specimens, besides those loaned to Kansas. Undoubtedly the most extensive collection of specimens is at the U.S. National Museum.

Several hundred specimens are also known from the American Museum of Natural History, University of California (Berkeley), Chicago Natural History Museum, Cornell University, State University of Iowa, Museum of Paleontology at University of Michigan, and foreign museums (e.g., at Exeter, England; Copenhagen, Denmark; and Stockholm, Sweden). Probably many other institutions also have Crawfordsville specimens, but only those mentioned are known at present.

DESIGNATION OF SPECIMENS

For the most part, specimens belonging to various museums are designated by their catalogue numbers preceded by initials of the museums responsible for them. In most cases these are clearly understandable (e.g., "UC" designates University of Cincinnati; "UCWM" University of Chicago, Walker Museum; "WC" Wabash College, etc.); however, slightly different treatment was given to specimens formerly at the Illinois State Museum (Springfield) and those belonging to the Worthen Collection.

The history of the Worthen Collection, which contains type-specimens described by MEEK & WORTHEN in reports of the Illinois Geological Survey (1866-90) and many types described by JAMES HALL (1858), and specimens belonging to the Illinois State Museum is rather long and complicated. According to Dr. LOIS KENT (personal communication), after WORTHEN's death, the Commission for the 1892 World's Fair (at Chicago) bought his entire private collection and took it and specimens from the Illinois State Museum to Chicago. New labels were made for all specimens and a group of paleontologists, including E. O. ULRICH, CHARLES WACHSMUTH, and FRANK SPRINGER were invited to study the collections. After the Fair, WORTHEN's specimens were given to the University of

Illinois and those belonging to the Illinois State Museum were returned to Springfield. Sometime later (about 1938-39), J. MARVIN WELLER obtained permission to transfer Illinois State Museum specimens to the Illinois Geological Survey collections. During the course of many moves the specimens in these collections became mixed, separated from their labels or lost. The University of Illinois Department of Geology, which ultimately became responsible for WORTHEN's specimens, recatalogued most of his fossils (some bearing Illinois State Museum numbers) but the Survey did not. The following method of designating these specimens has been adopted in this study: ISM (IGS) no. 000 refers to numbered specimens that bear only the original Illinois State Museum number, but now belong to Illinois Geological Survey; ISM (IDG) no. 000 designates specimens that bear the State Museum number but have not been recatalogued by the University of Illinois Department of Geology (most of these actually probably belong to the Geological Survey, as do those designated IDG (ISM) no. 000); IDG no. 000 refers to specimens in the Worthen Collection at the University of Illinois Department of Geology.

LOCATION OF AREA

Crawfordsville, located in west-central Indiana about 45 miles northwest of Indianapolis (Fig. 1), is the county seat of Montgomery County. Physiographically the area is part of the Tipton till plain in the glaciated northern part of Indiana and the surface of the county is covered by thick deposits of Pleistocene drift and Recent alluvium. Only where streams have cut through the Pleistocene deposits, or in man-made road and quarry exposures, can the bedrock be seen that underlies the county.

From data obtained during the course of this study, the region that yielded the vast majority of specimens was found to be along the west bank of Sugar Creek, north of Crawfordsville (SW $\frac{1}{4}$ Sec. 29, T. 19N., R. 4W).

The only record of other crinoid localities in Montgomery County is given on a map included in COLLETT's (1876) geological report of the county, and in a paper by BEACHLER (1892). Because some additional collections were made after these dates, all localities that yielded specimens cannot be determined. Information concerning the exact crinoid sites was purposely kept vague so that other collectors would not encroach upon good "digging" areas.

PREVIOUS STUDIES

Prior to 1859, when the first crinoid from Crawfordsville was described by LYON & CASSEDAY (69), only 70 species of crinoids had been reported from North America. Crinoid studies lagged behind investigations of these fossils in Europe, paleontological work in this country being concerned mostly with other groups of organisms. Virtually all researches

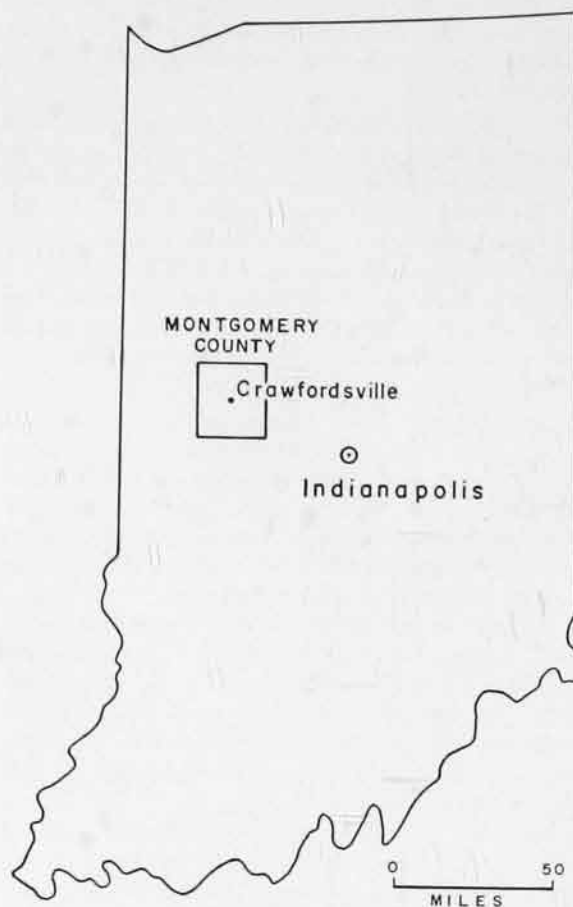


FIGURE 1. Outline map of Indiana, showing location of Montgomery County and Crawfordsville, the county seat.

on the morphology and classification of crinoids was done by Europeans; the little work published in this country consisted merely of some descriptions of new species.

Toward the end of the 1850's great interest and activity was aroused in American paleontology by the discovery of abundant, well-preserved crinoids in the "southern" and "western" states. Foremost were discoveries in Tennessee and prolific occurrences of crinoids in the vicinity of Burlington, Iowa. At about this same time other important areas were found, near Keokuk, Iowa; Louisville, Ky.; Alpena, Mich.; Richfield, Ohio; and Waldron, Hartsville, and Crawfordsville, Ind. Almost as rapidly as the new areas were discovered, specimens were described. During a seven-year period (1858-65) approximately 600 new crinoid species were proposed. This is particularly

remarkable when one considers that this period included the four Civil War years (1861-65).

It is not surprising that with this great interest in crinoids and the abundance of specimens collected, fierce competition arose between geologists who wished to acquire professional prestige by describing the new forms. A paleontologist's reputation and measure of success was determined by the number of new species he was able to describe. This emphasis was more or less common in paleontology until the 20th century, and even today it can be detected in some paleontological papers.

In 1859, approximately 23 years after the first crinoidal material was found at Crawfordsville and 17 years after active collecting of the crinoid-bearing beds was begun, LYON & CASSEDAY (69) published the first descriptions of Crawfordsville species. Four species of crinoids, based on specimens sent to LYON by O. W. COREY, were proposed by them, and in 1860 an additional species was named. In 1861, JAMES HALL, of Albany, N.Y., who had secured a number of crinoid specimens from E. O. HOVEY, another Crawfordsville collector, described six new species. During the decade 1860-70, several new forms were proposed (mostly without illustrations), and in this period the first extensive collections of crinoids from Crawfordsville were made. In the next two decades (1870-90) active collecting in the Crawfordsville beds continued, but comparatively few new species were described. However, in the 1890's, largely because of the efforts of the well-known paleontologists, S. A. MILLER and W. F. E. GURLEY, a number of new forms were named, and by 1900 nearly 90 per cent of the species occurring at Crawfordsville had been described. Table 1 summarizes the number of species described from this locality for designated periods of time, and indicates the paleontologists who proposed them. The list includes many species that now are considered to be synonyms, as well as species described from different localities, but it includes all species that have been noted as occurring at Crawfordsville. Forms described only from the Indian Creek locality have not been included in the table. The column reporting number of species includes not only forms originally described from Crawfordsville but other species subsequently identified in the Crawfordsville assemblage. The numbers marked by asterisks indicate forms that at the time of original description were reported to come from the Crawfordsville region.

Many early descriptions of new species were based

on a single specimen, or at most a very few specimens which commonly were not well preserved. Thus, early paleontologists generally were not aware of morphological variations within a species population. As a result, a strictly typological approach was taken by most of these paleontologists. Noteworthy examples can be found in many of MILLER's (86-93),

TABLE 1. Numbers of Crawfordsville Crinoid Species Described in Various Periods.

Years	No. New Species Described	Authors (no. of species described)
1858-59	10 (5*)	Hall (5); L & C (5).
1860-69	26 (18*)	Hall (9); Lyon (1); L & C (4); C&L (1); M&W (11).
1870-79	11 (9*)	M&W (5); Worthen (3); W&S (2); White (2).
1880-89	8 (5*)	Miller (2); W&S (1); Worthen (3); White (2).
1890-99	32 (24*)	Miller (6); M&G (22); W&S (4).
1900-46	7 (6*)	Kirk (4); Springer (3).

* Species which at time of original description were reported to come from Crawfordsville area. Names abbreviated as follows: CASSEDAY & LYON (C&L); LYON & CASSEDAY (L&C); MEEK & WORTHEN (M&W); MILLER & GURLEY (M&G); WACHSMUTH & SPRINGER (W&S).

and MILLER & GURLEY's (95-98) descriptions of monobathrid camerates. In order to justify the large number of new species that these authors proposed, they postulated that all specimens belonging to a single species must have had exactly the same number of arms. In 1896 MILLER & GURLEY (99, p. 22-23) stated their ideas as follows:

Anyone studying these forms (*Batocrinus*) must become convinced that the arm formula, in all cases, in this genus, is of specific importance. After having examined many thousand specimens belonging to this genus, we are free to say, that in no case have we found two specimens having a different number of arms, that agree in other characters, and hence the number of arms, as shown, in the calyx, before the arms become free, must rank in the first degree in determining the specific characters and in entitling the form to a specific name.

This approach to classification of crinoids has been shown by LANE (64) to be entirely unsound, because it results in clearly unnatural groupings of specimens assigned to given species. In studies by LANE and in the present one, the number of arms is considered among the most variable characters of batocrinid genera. MILLER & GURLEY's fallacious concept becomes equally apparent when some of their species from the same locality and of the same age are tabulated. For example, they described 26 new species of *Batocrinus* from the Burlington Limestone at Sedalia, Missouri, 19 from rocks of the same age at Burling-

ton, Iowa, and 28 from the Keokuk Limestone at Booneville, Missouri. Upon re-examination of these batocrinids LANE found that a majority of the species are invalid, as they represent mere morphological variations of previously described forms. Similar but less thorough studies have also been made of *Dolacrinus* (137) and *Agaricocrinus* (62).

EXPLOITATION OF CRINOID BEDS

DISCOVERERS—1832-59

At an early date in the settlement of the west, when the pioneer had just entered the wild forests, still occupied by wilder savages, a band of young missionaries, hopeful for the future of this region, and foreseeing its moral and educational needs, determined to found a school for collegiate education (COLLETT, 1876).

The history of discovery and exploitation of the Crawfordsville crinoid beds properly begins with the founding of Wabash College in 1832. Five young Presbyterian ministers, determined to advance Christian education on the frontier that western Indiana represented at the time, met in Crawfordsville that year to establish an institution of higher learning, the result of which was Wabash College. The first white settler in Montgomery County, WILLIAM OFFIELD, had come to the area only 11 years before.

One of the founders of the college, REV. EDMUND OTIS HOVEY (Fig. 4), became one of the two initial instructors in the new school. He soon developed an interest in science, especially natural history and geology, which he was to continue during the remaining 45 years of his life, all spent teaching at the college. This early establishment of a seat of higher learning in close proximity to the yet-to-be discovered crinoid beds was fortunate. The college provided facilities for collecting and storing specimens, but more importantly, many of the collections were made by students and faculty members of the college who had an interest in science and treated the specimens as something other than curios.

During excursions in the vicinity of Crawfordsville, HOVEY soon noticed many fossils, especially on slabs of limestone crowded with "encrinites stems and rings" that were common on gravel bars along Sugar Creek, or Rock River, as it was then known. As early as 1836, HOVEY was collecting fossils for the Wabash College cabinet and using them in his classes. He soon became an ardent collector of crinoids, and many of his specimens were loaned to, or exchanged with, individual paleontologists, notably

JAMES HALL and A. H. WORTHEN, who subsequently published descriptions of them. Under HOVEY's direction the college cabinet grew until it became the Hovey Museum, which occupied one of the campus buildings and contained one of the best natural history displays of its day. The crinoids in the museum collection remained at the college, although not on display, until 1950, when all but a small representative teaching collection were sent to the Chicago Museum of Natural History.

HOVEY never sold his specimens but through exchanges he added to the museum collection and gained scientific recognition for the college to which his life was devoted. His son, HORACE, recalled in later years that his father often complained that he never seemed to have time to put down the many new geological observations that he had made. Finally, after a continuing interest of 25 years HOVEY (1867) wrote a short paper describing the geologic setting of the fossil locality.

During the summer of 1842 an advertisement of a New York fossil collector came to the notice of HORACE C. HOVEY, the nine-year old son of the college professor. The collector offered \$5 a bushel for "encrinites" columnals and HORACE soon collected a bushel and his fee, which must have seemed a large amount of money in those days, certainly one that HOVEY (1883) could recall easily 40 years later. Among the fossils obtained that summer was a warty object "pronounced by the boys to be a petrified toad." This specimen was really a worn calyx of a batocrinid (Pl. 7, fig. 6), and is the first reported crinoid head found in the vicinity. HORACE HOVEY (Fig. 5) kept the specimen many years—it was in his possession in 1882—but at his death the fossil, along with other fossils in HOVEY's collection, was willed to Wabash College. The specimen now is in Walker Museum, University of Chicago.

No record of any more crinoid calyces or crowns collected between 1842 and 1851 has been found. During this span of time, however, two events occurred that were ultimately to have great impact on development of the fossil beds. In 1846 ORLANDO W. COREY moved to Crawfordsville from Pennsylvania. At the time of his arrival he was 41 years old, and his occupation has been given variously as machinist, gunsmith, and locksmith. Four years later DANIEL ALZO BASSETT enrolled as a freshman at Wabash College at the age of 30, an unusually late date to start college in those days. He was born and grew up in

Clinton, New York, where he was a millwright, but his family moved to Logansport, Indiana, shortly before he entered college. He and one of his younger brothers both graduated from Wabash college, attended Lane Theological Seminary in Cincinnati, and became Presbyterian ministers.

IRA CRANE and ROBERT K. KROUT discovered some good crinoid heads in 1851, at least one from a small ravine that ran into Sugar Creek along its northern bank about a mile north of town, near the same spot where H. C. HOVEY had found the first head. At that time KROUT was 15 years old, and CRANE probably was little older, since he was a good friend of HORACE HOVEY, a college junior of 18. KROUT, one of the most brilliant of the early graduates of Wabash College, retained an interest in natural history throughout his life, and two of his daughters later became famous writers and novelists.

Sometime during the 1850's, O. W. COREY developed an interest in the crinoids which were being obtained sporadically, mostly from float material, along Sugar Creek. COREY found molds of complete crinoids in sandy siltstones near the top of the bluff along Sugar Creek where the earlier specimens had been collected. Subsequently, he dug in the soft clayey siltstone that makes up the lower part of the bluff and discovered many fine crinoid crowns in a perfect state of preservation. COREY should be accorded recognition as the first person to demonstrate that crinoids can be collected directly from these rocks, without dependence on chance discovery of inferior specimens that had been freed by weathering. The bluff from which he obtained his fossils, and which was shortly to become a world-famous fossil locality, became known among the early collectors as "Corey's Bluff," in his honor. The name was probably employed informally by the collectors because records show that COREY never owned the property and no official recognition of the name was ever made. However, COLLETT (31) included it on his geologic map of Montgomery County, and the name will be used here as a convenient appellation for this famous locality in discussion that follows.

Some of COREY's specimens were sent to SIDNEY S. LYON of Jeffersonville, Indiana, and in 1859 LYON and S. A. CASSEDAY published the first descriptions of crinoids from the Crawfordsville beds. With this publication the scientific world was alerted to the quality and uniqueness of the Crawfordsville crinoids. The free-for-all was on.

FREE-FOR-ALL—1859-75

Definitive knowledge is lacking of fossil collectors' activities for much of the period from 1859 to 1875. It was during this time that collectors and paleontologists from all parts of the country began arriving in Crawfordsville to collect specimens of the crinoids or to obtain them from local collectors. There must have been some jealousy and secrecy on the part of already-established local collectors to preserve their favorite localities from invading foreigners. Sharp competition arose for acquisition of good specimens, both among paleontologists who wished to gain recognition by first descriptions of new species, and among professional collectors who offered prize specimens for sale. WACHSMUTH & SPRINGER (159, p. 19), in discussing the condition of crinoid investigations during this period stated that "... interest, often mingled with jealousy, was manifested by the men of science, who, anxious to publish the new forms, and feeling they might be preceded by competitors, brought out preliminary descriptions (commonly without illustrations) to secure priority of their species." During this period the majority of Crawfordsville crinoids were described, and thus it is not surprising that considerable modifications have proved to be needful when these fossils and the nominal genera and species to which they were first assigned came to be restudied.

Beginning in 1857, CHRISTIAN VAN DELOO came from New York State to collect in Montgomery County for JAMES HALL, although Crawfordsville crinoids described by HALL (41) in his first publication on these fossils were obtained by exchange or gift from EDMUND HOVEY. VAN DELOO seems to have been the first nonresident of the region to search extensively for crinoids, and according to records in the New York State Museum, he was back in the area in 1867, this time collecting crinoids four miles south of Crawfordsville. This locality probably was either at the mouth of Offield Creek, a spot mentioned by OWEN (1838) years before, but actually six miles southwest of Crawfordsville; or along Walnut Fork, three miles southeast of town. VAN DELOO's last trip to Indiana was in 1886.

At about the same time that VAN DELOO first came to Crawfordsville, CHARLES DYER, a professional fossil collector living at Mt. Harrison, near Cincinnati, became interested in the beds. He came to Crawfordsville and according to HOVEY (47) made extensive excavations "some years since." He also obtained

crinoids by exchange with the Hovey museum, because the museum catalogue has three pages of entries of fossils received from him on exchange, mostly Ordovician fossils from the Cincinnati region. The crinoid collection assembled by DYER was sold by him to the British Museum of Natural History and it represents the first large group of specimens sent abroad.

Dr. W. H. BARRIS, a medical doctor and early amateur paleontologist from Burlington, Iowa, also visited Crawfordsville during this period. He kept a notebook of "good localities for fossils: handbook of noted localities," that is in the Springer collection at the U.S. National Museum. His entry for Crawfordsville is as follows:

Crawfordsville, Indiana. Go north of village on railroad across a small creek and until you come to a large creek, go across the bridge and down to the creek on the left hand side. Follow a few rods along the bank and see places which have been quarried.

The fossils are almost always in seams, if not always. Take a man with pick and shovel.

As you go off from the railroad bridge to the left, go up to near the top of the bluff and look in sandstone much resembling our Chemung of Burlington of a yellowish color, for casts of crinoids, some of which are not only very complete but very beautiful.

These are found above the zones in which the [?true] crinoids are found. White indicated that another good locality was on Walnut Fork three miles from town but did not visit it.

See Rev. Mr. Hovey—ask for Corey and others who have collected.

These directions can still be followed. The bridge referred to is the Monon railroad bridge over Sugar Creek just upstream (east) from Corey's Bluff (Fig. 2). The reference to WHITE is clearly to CHARLES A. WHITE, who came to Crawfordsville to arrange for JAMES HALL to obtain some of E. O. HOVEY's crinoids for description (CLARKE, 30a, p. 294).

In 1864 FRANK H. BRADLEY started a collecting method that was to be used for the next 40 years. He was the first to enter on systematic quarrying operations for the crinoids. BRADLEY was a graduate of Yale University and upon notifying O. C. MARSH (a trustee of the newly organized Peabody Museum at Yale) of the extent of the crinoid beds, BRADLEY was told to secure a collection for MARSH. According to HORACE HOVEY (48), when BRADLEY reported to MARSH that "he had 1000 crinoids for which he wanted \$500 it naturally made MARSH hesitate and while he was hesitating my father stepped in and bought the entire lot for Wabash college! But it should be added that MARSH gave orders to have another 1000 obtained at once for Yale College and it was done."

Subsequently BRADLEY was Professor of Geology at the University of Tennessee.

During this period ORLANDO COREY was also active collecting and selling fossils to interested paleontologists. By 1867 he had sold several thousand specimens to the Smithsonian Institution, Harvard University, Yale University, and the University of Michigan, as well as to Wabash College. By 1870 many paleontologists (e.g. HALL, CASSEDAY, SIDNEY S. and VICTOR W. LYON, WORTHEN, and RICHARD OWEN) had personally visited Corey's Bluff for brief periods of time. COREY was assisted in this work by L. H. COREY, who also lived in Crawfordsville. The 1874 "People's Guide" for Montgomery County lists L. H. COREY as a "painter and collector of fossils and minerals; born in N.Y., 1834; settled in Montgomery county, 1870; Demo., Prot." Other fossil collectors refer to the "COREYS" of Crawfordsville as if they were related; O. W. COREY was 29 years older than L. H., and came to Crawfordsville 24 years earlier. Their relationship is unknown; perhaps they were uncle and nephew, or cousins.

The two COREYS contributed about one half of specimens that were photographed and assembled into plates but never published by S. S. LYON. These plates are now in the U.S. National Museum, and were intended to illustrate papers on Crawfordsville crinoids published by LYON & CASSEDAY in the 1860's. The plate explanations list specimens from the following cabinets: 18 from O. W. COREY, four from L. H. COREY, 12 from Wabash College, nine from the Illinois Geological Survey (Worthen collection), and one each from F. H. BRADLEY and JOHN COLLETT.

O. W. COREY seemingly spent so much time collecting and preparing crinoids that he neglected his profession of locksmith or gunsmith. HORACE HOVEY (48) recalled that "COREY [O. W.] was an excellent locksmith but nature meant him for a crinoid hunter, and he followed the bent of his genius to the detriment of his business until one day he sold me his entire collection numbering about 500 specimens. It was paid for by several subscribers." This collection became part of the Hovey Museum crinoid collection. If the "People's Guide" (1874) is correct concerning the year of COREY's birth (1805) he was 65 years old in 1870 and his active collecting must have been curtailed to some degree. Remarkably enough SPRINGER (136) recorded that COREY assisted CHARLES BEACHLER, then a boy of 16, in quarrying activities in 1886, when

the former would have been 82 years old. His assistance must have been mainly in an advisory capacity. The whereabouts or activities of either COREY after this date are unknown. No further record has been found of either of them in Crawfordsville.

During a two-year span from 1875 to 1877 a sharp change in the men involved in exploiting the crinoid beds occurred. HORACE HOVEY had left Crawfordsville to take up ministerial posts in New England, where he spent the remainder of his life. When he

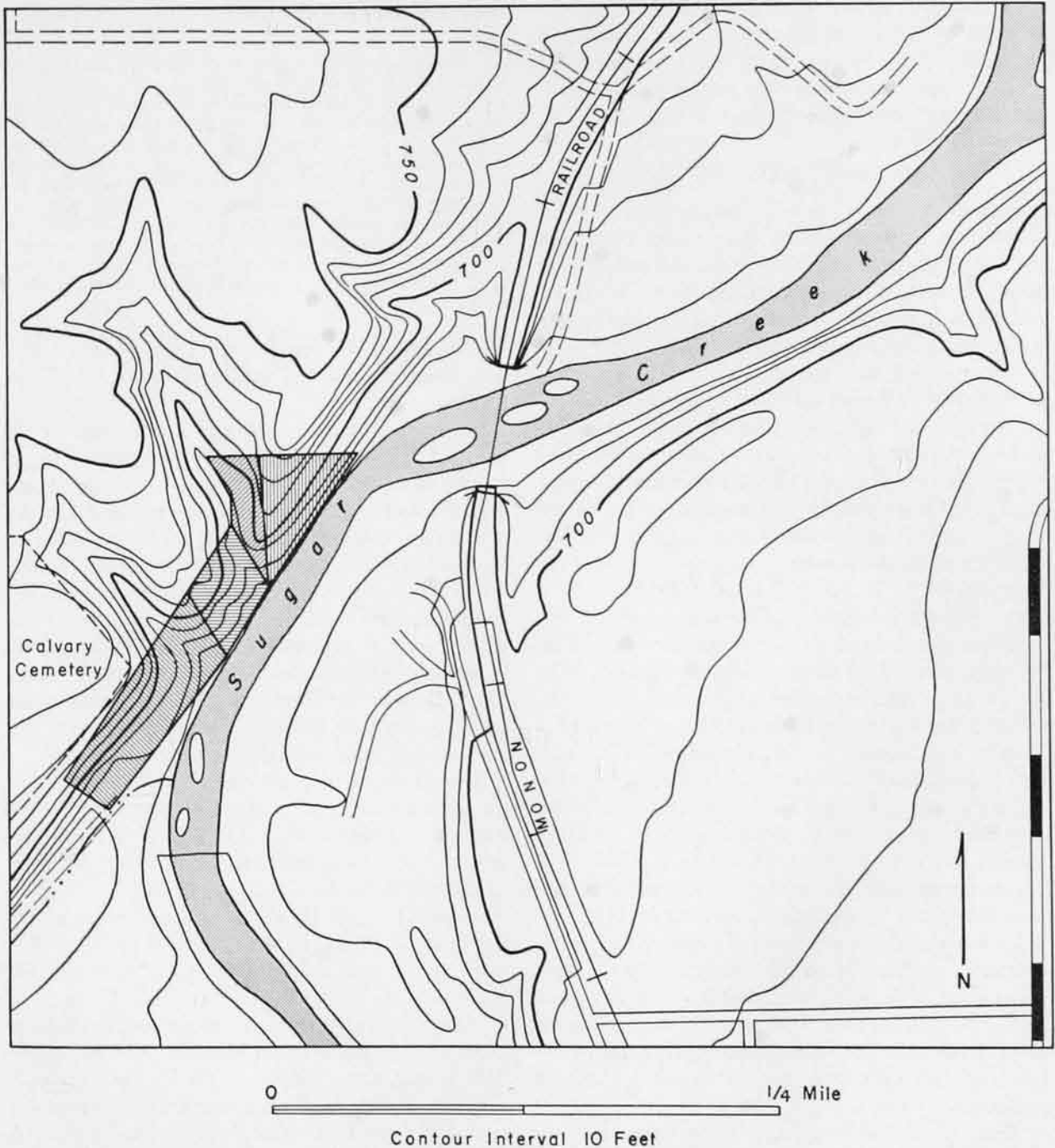


FIGURE 2. Topographic map of the SW $\frac{1}{4}$, T.19N., R.4W., Montgomery County, Indiana. Enlarged and modified from U.S. Geological Survey 7 $\frac{1}{2}$ minute Crawfordsville quadrangle (1956). Shaded area indicates location of land purchased for quarrying of crinoids (see Fig. 5).

left Indiana in 1861, he gave his crinoid cabinet, valued at \$1000, to Wabash College, although he continued to acquire some crinoids after that time. His father, EDMUND HOVEY, died in 1877 after long, devoted service to Wabash College; and the COREYS, BRADLEY, DYER and VAN DELOO pass from the scene. Their places are taken by a group of men who purchased the land on which the crinoids occur, who engaged in large-scale quarrying activities, and who assembled crinoid collections for sale. The day of the "big business man" in crinoid collecting had arrived.

NO TRESPASSING—1875-87

During all the years of collecting prior to 1875 Corey's Bluff was owned by three disinterested men who took no part in activities of the fossil collectors or notice of them. THOMAS SLATTERY, JOSEPH MILLIGAN, and M. I. ELSTON all owned part of the bluff along which the crinoids were being collected. In 1875 part of the quarried area was sold by the Elston estate to St. Bernard's church for the purpose of establishing a graveyard on level land above the bluff. This tract of 23 acres came down to Sugar Creek and included part of the area where the crinoids were found. In the same year DANIEL BASSETT purchased a one-acre parcel of land from THOMAS SLATTERY adjacent to and just upstream from the cemetery property. This was the first acquisition of land along Corey's Bluff by a person expressly for the exploitation of the crinoids.

BASSETT had lived in Crawfordsville since 1866, when he came there from a pastorate at Lodi, Wisconsin, to accept the position of Principal of the preparatory department of Wabash College. Presumably BASSETT had been an active collector before his purchase of the land, and one wonders if his acquisition did not result in some ill-feeling on the part of other collectors who earlier had had free access to the bluff. BASSETT consolidated his holdings by purchase of a 1.66-acre tract from St. Bernard's church, and a one-acre tract from JOSEPH MILLIGAN, both in 1878. He did not have sole ownership of the quarry sites, however, because PAUL MOHR, of Cincinnati, also bought a small part of the bluff (one acre) from the church in 1876, although MOHR's deed was not recorded until 1881. So, by 1878 the entire collecting area was in the hands of two men interested in assembling crinoid collections for sale.

From the available evidence, MOHR's purchase was made on behalf of FREDERICK BRAUN, also of Cincinnati, who had come to Crawfordsville for the express

purpose of entering large-scale quarrying of crinoids. The two men probably had some kind of understanding regarding distribution of quarrying costs and allocation of specimens. This is borne out by a privately printed advertising circular prepared by BRAUN after he had obtained a large collection of fossils at Crawfordsville. It states:

... Wishing to procure a collection of Crinoids I inspected the celebrated locality known as Corey's Bluff. . . . The Crinoidal bed had been worked by former collectors as far as practicable without removing the overlying rock and loose material, and there was no choice left but either to abandon the object or to make a large excavation and remove about 30 feet of rock; the ground belonging to a graveyard the same had to be bought. To go under these circumstances into the enterprise on a small scale or with a small force of men was impracticable and I had to employ for 3 months 20 to 30 men and several carts and horses to reach the crinoidal strata. The expense exceeded by far my calculations and means, and only by the liberal pecuniary aid of friends of science I could accomplish my object.

Whether MOHR was the only "friend of science" who provided financial assistance to BRAUN is not known.

In the circular BRAUN offered four collections for sale: a large one, consisting of 49 specimens of 23 species of crinoids and 19 species of other invertebrate fossils from the beds, was offered for \$200; the next largest collection, consisting of 30 specimens of 15 crinoid species, was listed at \$100; a third, for \$50, contained 20 specimens of 10 common crinoid species; and for \$15 one could obtain 10 specimens representing five species. BRAUN could offer more than one set of the two smallest collections, because he says "about 6 collections can be furnished—the largest part of the specimens include about 10 species, of which I am able to furnish many excellent suits."

Purchasers of these collections paid from \$1.50 a specimen for the most common crinoids offered in the smallest collection to about \$4 a crinoid in the largest collection that contained the greatest variety of fossils. At the end of the circular BRAUN offered as references "the Custos of the Palaeontological Museum of the University of Berlin, D. C. Damer and Professor Beyrich, having sold a collection to the above named institution."

The collections offered in this circular, in addition to the one sold to the Berlin Museum, other collections BRAUN may have sold, and crinoids that probably were turned over to MOHR, mean that BRAUN probably recovered many hundreds of crinoids during this collecting period. MOHR sent many Crawfordsville crinoid specimens to JAMES HALL in 1884, the majority

of which are now in the Walker Museum, University of Chicago. This collection may represent all or part of MOHR's share of the material obtained from BRAUN's excavations, and if so, this means that the summer's work referred to by BRAUN in his circular, was undertaken some time between 1876, when the land was purchased, and 1884, perhaps in 1881 when the deed for the land was recorded in Crawfordsville. The circular quoted above is listed by NICKLES (115) as published in 1873, although no date was given on the circular. It seems highly unlikely that BRAUN's collecting was done so early, especially in view of the fact that he mentions a "graveyard" and the church did not buy the land for that purpose until 1875.

During the same time interval, from about 1875 to 1883, DANIEL BASSETT was busily engaged in quarrying on his land and in preparing collections for sale. BASSETT employed several workers intermittently to dig out the fossils for him, although he did all of the final cleaning of the crinoids himself. He built a small house on premises adjoining his home, where he prepared and stored the crinoids prior to their sale. Of particular interest is the fact that a large number of specimens collected and sold by him were preserved on large slabs containing both crowns and attached stems (rarely roots). Previous collectors, and also most subsequent ones, were primarily interested in the dorsal cups and crowns, and thus commonly sacrificed the stems and roots to get the more prized (and valuable) "head" parts of the crinoids. The slabs collected by BASSETT also represent almost the only specimens in which nearly complete calcareous remains of the organisms (crowns and stems) can be found, and are the only true record of which species lived in association with each other. BASSETT advertised his crinoid collections by means of a privately printed circular similar to the one BRAUN used. At least two editions of this circular were distributed, and a copy of the second edition, printed in 1882 or 1883, is in the Springer library. This circular contains copies of letters sent to BASSETT by recipients of his fossils that amply illustrate the excellence of the preparatory techniques that he used. The circular (in part) is as follows:

WABASH COLLEGE

Crawfordsville, Indiana

Dear Sir:—A former circular respecting the Crinoids of this locality has been received with so much interest by lovers of science and persons engaged in collecting cabinets, both public and private, that I have been constrained to issue this second edition, indulging

the hope that it may be of service to others desirous of securing a collection of these beautiful and rare fossils.

It is now generally admitted that the crinoids of the Crawfordsville beds are not surpassed in beauty, perfection and variety by those of any other locality in the world. They were evidently buried alive in the ocean ooze, which, having solidified around them has preserved them perfectly, even to the minutest particular. And such is the nature of the rock in which they are now imbedded that with skillful management in removing them from the quarry, and by experience and great patience in working them out they may be restored in almost as perfect a condition as when buried in the bottom of the ocean thousands of years ago.

These crinoid beds are now mostly in my possession, and have been quite extensively worked under my own personal supervision. The knowledge thus obtained, together with much experience in dressing the specimens and preparing them for the cabinet, has enabled me to improve upon previous methods to such an extent as greatly to increase the beauty and value of the specimens. The following testimonials will afford some idea of my success in this particular and of the character of the specimens obtained in this locality:

STATE OF INDIANA

Department of Geology and Natural History
Indianapolis, Feb. 28, 1882

Prof. D. A. Bassett,

The lot of 300 crinoids, secured by your kindness, has been placed in the State Museum, and is quite an addition to our crinoidal exhibit. The specimens show great care and skill in their dressing. Your locality is one of the richest illustrations of the strange wondrous life which thronged this chosen spot in the depth of the ancient sub-carboniferous oceans, and better than words or pictures, their preserved forms show the life of the Keokuk Group.

Truly, Your Friend,
JOHN COLLETT, State Geologist.

MUSEUM OF WABASH COLLEGE

Crawfordsville, Ind., March, 1882

We have just secured from Prof. D. A. Bassett, a large series of the crinoids of this vicinity. No one can appreciate the difficulty of working them out without having attempted it, nor the rare beauty of these specimens without having seen them. The writer has seen the crinoids of all the largest collections in this country, and they contain nothing that can compare in elegance with these specimens of Professor Bassett's preparation. He brings to the work, the finest beds in the country, a practice and skill that are inherent, but improved by long experience, and, what is perhaps most important, a scientific knowledge of the subject, which makes him perfectly familiar with the demands of a museum. The only advertisement he needs, is a sight of his specimens, and the most fastidious collector will be more than satisfied. The museum of Wabash College is always open to any one desiring proof of these statements.

JOHN M. COULTER,
Professor of Geology

New Haven, Conn.

Prof. D. A. Bassett:

Dear Sir:—Accept my thanks for the exquisite specimens just received. I have laid them beside the water-worn pebble I picked up, thirty-nine years ago, where your quarry now is, and which was probably the first crinoid found in that locality. I congratulate

you, not only on your possession of the best crinoid bluff in America, but also on your improved process of cleaning, by which results are attained superior to anything of the kind I have seen, even in the museums of Harvard and Yale.

Yours Very Truly,
H. C. HOVEY

WOODWARDIAN MUSEUM

Cambridge, England

Prof. D. A. Bassett:

Dear Sir:—I have just unpacked the box of specimens which arrived in perfect condition as to its contents, and may say at once that we are very much pleased with the specimens. The two large slabs especially are marvels of skill and patience in working and developing these delicate fossils. We consider that we have been very generously treated, for the time and labor expended must have been something enormous.

Yours very truly,
E. B. TAWNEY, A.M.

Louisville, Kentucky

Prof. D. A. Bassett:

Dear Sir:—The box of crinoids came safely to hand, and they are indeed *beautiful*. All prove perfectly satisfactory. My opinion is, that the Crawfordsville crinoids are not only superior to all in the west, but are the best in the world. In compliment to your mode of dressing, I must say that the specimens have been prepared with wonderful skill, preserving not only the structure of the animal but every tender fiber. And the packing was so carefully done that not a single specimen has received the least injury.

Yours very truly,
C. C. GRAHAM, M.D.

McGill University, Montreal

Prof. D. A. Bassett,

Dear Sir: The specimens arrived safely and are satisfactory.

Truly yours,
J. W. DAWSON

BASSETT then goes on to say that he can furnish crinoid heads at from 75 cents to \$3 each according to size, quality, and species, and that fractured specimens are furnished at 25 to 75 cents each. For references he lists at the end of the circular the names of Rev. JOSEPH F. TUTTLE, President of Wabash College, and HORACE C. HOVEY, Fair Haven, Connecticut.

BASSETT also sold collections to the University of California, Berkeley; Cornell University; and the American Museum of Natural History. These sales may have resulted from the second advertising circular quoted above. In a letter to Professor JOSEPH LE CONTE, chairman of the geology department of Berkeley, BASSETT described the collection offered for sale at \$1000, quoting from his circular, "If you will notice, my circular states that I cannot be responsible for safe carriage," and he also mentioned details of his successful negotiations with Prof. HENRY S. WILLIAMS of Cornell.

The collection BASSETT sold to Berkeley consisted of 121 "packages and pieces," several of which were slabs of rock that contained up to 16 crinoid specimens, many with the stem and crown intact. Some packages contained several small slabs or individual specimens. While \$1000 does not seem a large sum of money today for such a collection, it can be noted that BASSETT's annual salary from Wabash College at this time was \$1500, and that his commercial activities in the sale of these crinoid collections must have made him among the more well-to-do members of the college faculty.

BASSETT also sold small lots of specimens to individual paleontologists. In one of CHARLES WACHSMUTH's notebooks (in the Springer collection) he lists purchase of \$19 worth of crinoids from BASSETT, and \$3 for 10 specimens from "the Correys." Not all of these specimens were from Crawfordsville, however, because in a detailed list of the specimens WACHSMUTH cited several from Bono, another well-known locality for crinoids in Indiana.

In 1882 BASSETT notified Wabash College authorities that he "would prefer to represent the college in the field for the coming year, at least for the greater part of the year, and that perhaps he would not want to teach anymore" (Minutes of the Board of Trustees, July 4, 1882). The trustees agreed that BASSETT would be employed as College Agent for the coming year except for time he might want to be used in his own affairs. At this time BASSETT was 62 years old and it seems that his crinoid "business" was taking up more and more of his time. In June, 1883, BASSETT was approved as Financial Agent of the college until October 1, and the executive committee of the trustees was authorized to excuse him from further service after that date at their discretion.

By October 8 of that year BASSETT had tendered his resignation to the college and announced his intention to go to the Pacific coast on doctor's advice because of Mrs. BASSETT's health. The BASSETTS moved to southern California in 1883, and the Wabash College catalogue for 1883-84 lists him as a minister at Colton, California, but the next year's catalogue has him as a minister in Crawfordsville. At any rate, he returned to California and died there on May 28, 1887, at La Crescenta, where, according to his obituary (Crawfordsville *Saturday Journal*, June 4, 1887) he owned a prosperous fruit farm near Pasadena.

BASSETT's will provided that Wabash College should have the privilege of buying the land on Sugar Creek

known as the "crinoid beds or grounds" at \$50 an acre. It directed that his collection of specimens be sold and the proceeds divided between his wife and daughter. BASSETT's collection was sold by the executor of his estate in August, 1888, for \$200 to Yale University. The collection included "one lot of slabs and unworked specimens, six hammers and picks, and 23 stone chisels."

Wabash College did not exercise its option to buy BASSETT's quarry site, Mrs. BASSETT died in 1888 and her daughter deeded all of the crinoid land for one dollar to MARY HOVEY (EDMUND HOVEY's unmarried daughter and older sister of HORACE HOVEY) in 1889. MARY HOVEY sold part of this land (Fig. 3) to MICHAEL ZELLER in 1889 and the rest of it remained in the HOVEY family until it was deeded to Wabash College by EDMUND O. HOVEY, HORACE's son, and director of the American Museum of Natural History, in 1925.

One week after BASSETT's death was announced in the Crawfordsville papers, an article (*Argus News*, June 13, 1887) appeared that gives the only known clue to the preparation methods used by BASSETT that allowed him to work out such excellent specimens of crinoids:

In speaking of the late Prof. Bassett Miss M. H. Krout [Mary Hanna Krout, a noted journalist and daughter of Robert K. Krout] of the *Terre Haute Express* says, she recalls a singular employment with which he occupied himself out of his regular work hours. This was the preparation of crinoids for the museums of eastern colleges and for several European institutions. The most important collection was sent to the London Museum. . . . Paleontologists are aware of the difficulty of preparing perfect specimens. Other people do not know that this is accomplished by soaking the clay which contains the fossils, in water for some time until it becomes sufficiently soft and the specimen can be cleaned with a nail brush or toothbrush. . . . This collection, I think, was purchased entire by Wabash College and is in its museum.

The last part of this story is in error because the collection was sent to New Haven, Connecticut, by the administrator of the estate. The experience of the senior author of this paper confirms that prolonged soaking in water is the only satisfactory way to soften the matrix surrounding the crinoids so that they can be satisfactorily prepared. Sale of a collection to the London Museum (British Museum of Natural History?) has not been verified from any other source. Miss KROUT may have had reference to the collection sold to the Woodwardian Museum in England.

Discussion of this period would be incomplete without mention of the size and location of the several pieces of ground that were purchased for quarrying purposes. The old deed records contain few references

to surface features that can be recognized today with certainty, but they provide enough information to allow reasonably precise delineation of the quarry sites. None of the land has been resurveyed since the original purchases in the 1870's, and successive ownerships of the land have carried the old records forward. All of the deeds contain numerous references to certain trees that were used to establish turning points for each survey (e.g. "white oak 24 inches in diameter, south 48 west 39 links, for a beginning corner"). Because most of these trees can no longer be recognized with certainty and several were surely destroyed in later quarrying, references to them are deleted from the deed records quoted below.

The two pieces of land purchased by BASSETT from THOMAS SLATTERY in 1875 and JOSEPH MILLIGAN in 1878 have a common beginning point and a common boundary. They also are the only two deeds that are based on a precise reference point in terms of the section boundaries in which the land occurs. These two deeds are as follows:

Beginning at the west $\frac{1}{2}$ mile corner of Sec. 29, then east forty rods and twelve links, thence south 71 rods and four links to a stone for a beginning corner, and running west thence east $15\frac{1}{2}$ rods to an elm tree standing on the edge of Sugar Creek, thence down said creek south $35\frac{1}{2}$ west distance $25\frac{1}{2}$ rods to a stone at the mouth of a hollow, thence north 21 rods to place of beginning. 1 Acre.

Beginning at the west $\frac{1}{2}$ mile corner of Sec. 29, thence east forty rods and 12 links, thence south 71 rods and four links to a stone for a beginning corner; thence west 2 chains and 12 links to a stake in a ravine, thence south 30 east two chains to a stake, thence south 97 links, thence south 31 east 12 poles and 21 links to Sugar Creek thence north 21 rods to beginning, containing $88/100$ acre.

The common beginning point for these two pieces of land was used as basis for establishing the location of all of the parcels of land on the present topographic land surface (Fig. 3). It is clear that the first of the two areas was triangular in shape, and that the second was an irregular tract, elongate in a north-south direction. The two areas have a common southern point "at the mouth of a hollow" along the edge of Sugar Creek, because of the same distance and direction of the last limb of the boundaries in each deed. Because of the location of the starting point, which can be accurately determined, this hollow must be the long ravine that is encountered first downstream from the railroad bridge over Sugar Creek. The first turning point of the second deed is a "stake in a hollow," which must be in the same ravine. The irregular west boundary of the second piece of land closely follows the present bottom of this ravine, and must have done so originally, although this is not stated in the deed. The error of closure on the first deed is insignificant, but is 45 feet, with error in both distance and angle, on the "south 21 east, 12 poles and 21 links" edge of the second deed. In Fig. 4, where

the tracts are plotted on the present land surface, this error of closure is corrected, but it has been left on the enlarged diagram of the tracts (Fig. 3).

The next southwesterly piece of ground was that purchased by PAUL MOHR in 1876 (where BRAUN quarried) and sold to FRANK SPRINGER in 1886. This land was bought from St. Bernard's church shortly after the church had acquired the land, and was off of the east end of the 23-acre tract which the church originally owned. The deed is as follows:

Beginning at low water mark in a ravine on the north bank of Sugar Creek, being the first west of the L.N.A.&C. [Louisville, New Albany & Chicago, now Monon] railroad bridge on the north bank of Sugar Creek and said ravine being the east boundary of the land known as belonging to the Catholic cemetery ground, thence west along low water mark 209 feet thence north 209 feet, thence east parallel with low water to center of ravine 209 feet thence south along center of ravine to place of beginning. One Acre. Subject to right of Rev. Bishop Dwenger to remove any trees.

This deed confirms that the ravine "first west of the . . . railroad bridge" is the same ravine in that position today, and the one that is situated along the west edge of the land purchased by BASSETT from SLATTERY and MILLIGAN. It also establishes that the east boundary of the cemetery ground at one time extended this far east. This is an important point because the present east boundary of the cemetery is along the edge of the next ravine to the southwest (Fig. 2), a potential point of confusion in deciphering the locations of these tracts of land.

Of the original four purchases, the one remaining is that of BASSETT from St. Bernard's church in 1878. The beginning point for this parcel of ground was in the center of a ravine at low-water mark, along Sugar Creek 200 feet downstream from the east line of the tract known as St. Bernard's cemetery. This would put the beginning point within nine feet of the southwest corner of the MOHR-SPRINGER land and coincides closely with the present location of the mouth of the second ravine along the bluff downstream from the railroad bridge. The deed is as follows:

Southwest quarter of Sec. 29, off eastern part of the tract known as St. Bernard's Catholic cemetery and described as follows: beginning at a point in the center of a ravine at low water mark on the north bank of Sugar Creek. Said beginning point being down said creek 200 feet from the point where the east line of said cemetery runs into said creek; thence north 21 west three chains and 31 links to a stone, thence south $35\frac{1}{2}$ west 7 chains and 45 links, thence south 75 east two chains to the center of a ravine, thence north $39\frac{1}{2}$ east four chains, thence north 40 east one chain and 75 links to place of beginning. 1 and $66/100$ acres more or less.

This piece of ground is an elongate area with long dimension parallel to Sugar Creek. The southwestern turning point of the survey "in the center of a ravine" coincides fairly closely with the present position of a small spring-fed stream that runs into Sugar Creek below the bluff on which the cemetery is located. This

area was divided in 1909 into two smaller tracts, and the deed for the southwestern of these two parcels is as follows:

Beginning at a point two chains, $87\frac{1}{2}$ links, south 40 west of a point in the center of a ravine at low water mark, said point being 200 feet down creek from where east line of said cemetery runs into creek; thence north 30 west 2 chains and 42 links; thence south $35\frac{1}{2}$ west four chains and 8 links; thence south 57 east two chains; thence north $39\frac{1}{2}$ east two chains and $87\frac{1}{4}$ links to place of beginning. $75/100$ acre more or less.

The survey for this deed probably is in error (Fig. 5), as the area most likely should have been shifted farther southwest to match the original boundaries of the BASSETT tract.

It should be pointed out that the sizes, shapes, and locations of these pieces of land are erroneously shown in the Montgomery County plat book for north Union township. The land obtained by BASSETT from SLATTERY and MILLIGAN is shown in this book as a two-acre rectangular tract on either side of the railroad on the north bank of Sugar Creek (inset, Fig. 3) and the MOHR-SPRINGER land is shown in approximately the true position for the BASSETT land. These errors have been perpetuated in county plat books and land maps since at least 1917, when the Standard County Atlas of Montgomery County (G. A. Ogle and Co., Chicago, North Union Twtnshp., p. 24-25) shows the same distribution of land ownership. It was not until we consulted the Security Abstract and Title Company's plat book in Crawfordsville, in which the land locations and shapes are correctly shown, that the errors were realized and the original deed records consulted. The land along the north bank of Sugar Creek upstream from the tracts discussed above has been in the possession of the DETCHON family of Crawfordsville for many years, and in 1931 land along the north bank of Sugar Creek, extending 300 feet west from the railroad bridge, was subdivided by the DETCHONS and is now owned by two other parties.

The BASSETT-SLATTERY-MILLIGAN land was retained in the HOVEY family until 1925, as mentioned above, and is now owned by the Wabash College Foundation. The MOHR-SPRINGER parcel was disposed of by SPRINGER in 1917, 11 years after BRAUN's last quarrying activities there; it has had several owners and is now in the possession of HAROLD E. and MILDRED M. HAMM of St. Petersburg, Florida, who also own the adjacent part of the original Bassett tract that was purchased from the church. This land had been acquired in 1889 by MICHAEL ZELLER from MARY HOVEY. The land remained in the ZELLER family until 1909 and presumably was exploited for crinoids by MICHAEL ZELLER until his death in 1896, and perhaps by his son, MICHAEL E., after that date. In 1909 the land was divided, as mentioned above, and the southwestern part was acquired by the TOBIN family of Crawfordsville in 1910; it has remained in the hands of

this family since, being currently owned by ROBERT FRIER, grandson of JULIA TOBIN ROCHE, one of the previous owners.

After BRAUN had completed his early quarrying activities at Corey's Bluff, MOHR's land was presumably

used by MICHAEL ZELLER, a local resident of Crawfordsville, to obtain a collection of crinoids. HOVEY (48) says "Zeller's extensive collection, is, I believe, from Braun's bank and contains numerous fine specimens." An article in the Crawfordsville *Saturday Journal* two weeks earlier

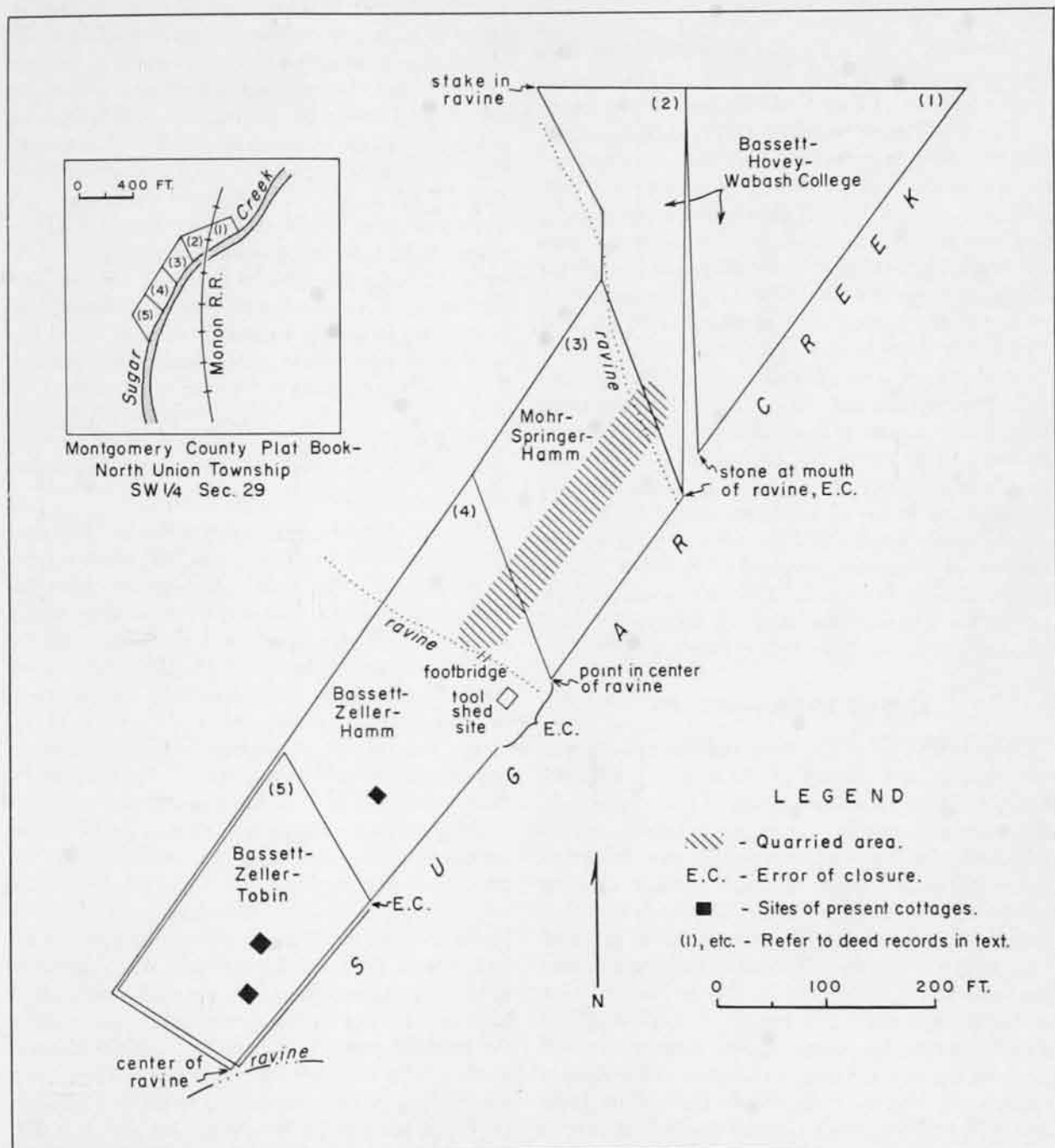


FIGURE 3. Tracts of land near Crawfordsville, Indiana, purchased for excavation of crinoids showing successive ownerships, location of quarry sites, important survey points, and topographic and cultural features. (Inset: Generalized map of SW 1/4 Sec. 29, T19N., R.4W., Indiana, taken from Montgomery County Plat Book, showing erroneous location of land plots.)

than HOVEY's letter erroneously cited ZELLER as owner of the bluff and credited him with a crinoid collection numbering between 2000 and 3000 specimens. BASSETT must have complained about this error, because he was the owner of most of the bluff, and the next week another article in the paper correctly stated that BASSETT was the owner.

MICHAEL ZELLER came to Crawfordsville in 1858, having been born in Bavaria in 1829 or 1830. He was a tavern owner in Crawfordsville for many years, although the "*People's Guide*" (1874) euphemistically lists him as a "restaurateur." He must have interested himself in the crinoids soon after arriving in Crawfordsville, and by 1883 he clearly had accumulated a large fossil collection. CHARLES WACHSMUTH recorded in his notebook (U.S. National Museum) that he (or acting as agent for FRANK SPRINGER?) purchased a collection of Crawfordsville crinoids in 1885 for \$620. This must have been a large collection and since BRAUN was not active at this time, and BASSETT had permanently departed for California, WACHSMUTH may have acquired this collection from ZELLER. SPRINGER (136) stated that he purchased a large collection of crinoids from ZELLER in 1880, and this may be the same group of fossils mentioned by WACHSMUTH, even though the dates are not the same. In another of SPRINGER's notebooks (probably for the period 1886-89, because he also mentioned field expenses for CHARLES BEACHLER, see below) he noted "ZELLER's collection from Indian Creek, \$400."

END OF AN ERA—1887-1906

The latter part of the 19th, and the first years of the 20th, century centers on the activities of FRANK SPRINGER (Fig. 6) in exploitation of the crinoid beds. SPRINGER was one of the greatest known crinoid specialists, and his work spanned the time from first systematic classification of fossil crinoids to more modern times when much of the taxonomic work had been done and researchers' attention turned to evolution and stratigraphic distribution of these fossils. SPRINGER was a lawyer and rancher in New Mexico, where he accumulated a fortune that allowed him time to pursue his paleontological interests, as well as to put together the largest and most comprehensive crinoid collection ever assembled. During the 1860's and until 1897 SPRINGER's research and collection were merged with those of CHARLES WACHSMUTH of Burlington, Iowa, and these men together produced the Revision of the Palaeocrinoidea (1880-86) and a

great monograph on the Crinoidea Camerata (1897), the latter published shortly after WACHSMUTH's death. In 1911 SPRINGER moved his collection and library from Burlington to the U.S. National Museum, their present location.

Prior to 1887, WACHSMUTH and SPRINGER had obtained all of their specimens of Crawfordsville crinoids by purchase of already collected material, or perhaps to some extent by exchange. Both men visited the town from time to time, but mainly to buy specimens, as no records exist that either one collected at Corey's Bluff. In 1886 SPRINGER paid \$40 for purchase of the acre of land that MOHR had owned along the bluff; MOHR was living in Alabama at the time the deed was recorded. In 1887 SPRINGER hired a young boy of 16 named CHARLES BEACHLER to quarry on his land during the summer, subsequently (1920) reporting that young BEACHLER was assisted by O. W. COREY; as mentioned above, since COREY would have been about 82 years old at the time perhaps he merely offered advice to the boy. Although inactive in later years, COREY had undoubtedly seen all of the previous excavations, the first ones of which had been made before BEACHLER's birth in 1870.

CHARLES SUMNER BEACHLER (misspelled BEECHLER in THOMPSON, 1886 and BEACHLER, 1887) was born in Crawfordsville. His father died shortly after his birth, leaving to his widow the care of their young son. BEACHLER developed an early interest in the crinoid beds and at the age of 15 (1886) had a small pamphlet privately printed describing the history of the crinoid beds; this was dedicated to "Capt. O. W. COREY, the pioneer in practical geology . . . in recognition of his services to science." Much of the information, some of it as direct quotation, contained in this booklet and in BEACHLER's first article on the famous locality (*American Naturalist*, 1887), was taken from HORACE HOVEY's letter in the Crawfordsville newspaper in 1883. BEACHLER enrolled in the junior class of the Wabash College preparatory department in 1886, and the next year was a freshman in the college, but taking only a partial course. After his first year of college he quit school, probably under the financial pressure of providing for his widowed mother, who was listed in the *People's Guide* as a dressmaker. At any rate, he became the first regularly employed collector for SPRINGER, who paid him \$245 for expenses and wages while quarrying at Corey's Bluff during the summer of 1887 and \$650 for three summers' field expenses and wages from 1888 to



FIGURE 4. Edmund O. Hovey, 1801-1877.



FIGURE 5. Horace C. Hovey, 1833-1914.

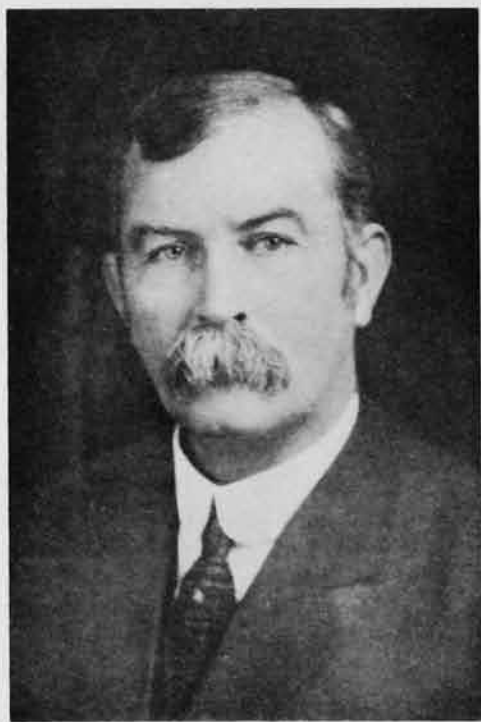


FIGURE 6. Frank Springer, 1848-1927.



FIGURE 7. Braun quarry operated for collection of crinoids at Corey's Bluff on Sugar Creek, near Crawfordsville, Ind., summer of 1906. (Photograph courtesy of United States National Museum.)

1890. During these summers BEACHLER discovered and collected from the famous crinoid beds along Indian Creek in the southwestern part of Montgomery County, and in addition, collected crinoids from the well-known Waldron beds (Silurian) and other localities in Indiana, Missouri, Kentucky, Tennessee, and Minnesota. Specimens collected by BEACHLER all became part of SPRINGER's private collection and are now deposited mainly in the U.S. National Museum, but some are at the State University of Iowa and the Museum of Comparative Zoology at Harvard University.

BEACHLER was an ardent geologist and fossil collector and by 1893 he had published four short papers on the crinoids and stratigraphy of Montgomery County, as well as on other topics. In 1892 or 1893 he went to Georgia to teach geology and to work with the Georgia State Geologist, J. W. SPENCER, but shortly he returned to Indiana, apparently in poor health. BEACHLER died on April 5, 1894, at the age of 23, an untimely death for a promising young scientist, who even at this early age was being considered as the next State Geologist of Indiana. In his short lifetime BEACHLER put into print more information on the stratigraphy of the crinoid beds in Montgomery County and their correlation with other strata on both sides of the Illinois basin than all of the published data on these subjects before or since.

Corey's Bluff remained idle after BEACHLER's time until 1906, when SPRINGER retained the veteran collector FREDERICK BRAUN, who by this time was 65 years old, to return to Crawfordsville and open a quarry on the same site that BRAUN had collected so successfully almost 30 years earlier. During the summer of 1906 BRAUN shipped 115 cases of crinoids to SPRINGER at Burlington, Iowa. SPRINGER (136) stated that BRAUN exhausted the locality for any future systematic collecting, although it is doubtful that this is true. During the summer BRAUN had four photographs taken of the quarrying operations for SPRINGER, one of which is reproduced here (Fig. 7). These pictures (in the Springer library) are the only documentary evidence of how the quarrying operations were accomplished. Each picture shows BRAUN (presumably the old gentleman with a mustache, pith helmet, and cleanest shirt) as well as seven workmen and a waterboy with bucket and dipper. A large area was stripped down to fresh rock and within this space narrow trenches were dug, both perpendicularly and parallel to the banks of Sugar Creek. The trenches

probably were exploratory in nature, serving to discover layers with abundant crinoids. At the close of the 1906 operations by BRAUN the exploitation of the famous crinoid beds passed into history. Although sporadic discovery of a few crinoids by casual collectors has surely taken place over the years, little or no systematic collecting has been done since that time. Corey's Bluff is now grown over with trees and weeds and only traces of the years of collecting can now be detected. A few of the local older residents of Crawfordsville have vague recollections of the past activity there, and those that do will tell you that "some German came here years ago and got them all," or that somebody dynamited the bluff and destroyed or buried the fossils forever. These half-remembered tales may have some basis in truth, making note of the German ancestry of BRAUN and perhaps MICHAEL ZELLER.

If one examines Corey's Bluff carefully today, traces can still be seen of the former quarries. On the east or upstream side of the large ravine that marked the original east line of the cemetery, on BASSETT's eastern tract of land, the remnants of a large trench and high rock pile can be seen. The trench extended from the ravine edge eastward, parallel to the creek, for about 35 feet and must have once been about 20 feet deep on the bluff side. The shale heap beside it has a tree about 14 inches in diameter growing on top of it, indicating that this site may have been one of the earlier diggings, perhaps BASSETT's. The main crinoid-yielding bed, about 5 feet thick and 24 feet above present creek level where exposed in the side of the ravine next to the trench, can still be collected. The junior author of this paper collected six good crinoid crowns at this spot during the summer of 1963.

This trench is the easternmost evidence that could be found for the old diggings. From this ravine westward to the next ravine, the bluff is set back about 30 feet from the bluff on either side, and has a conspicuous flat area in front of it. This land configuration clearly marks much of the important quarrying that was done over the years. Most of this land is on the MOHR-SPRINGER property. Ravines west of this part of the bluff show no outcrops of crinoidal siltstones, nor is there any sign of former digging activity. If correct, this would mean that only the southwestern corner of BASSETT's eastern land and the eastern part of the land (east of the second ravine) that he bought from the church was utilized for collecting. In terms

of value received, MOHR and SPRINGER had made by far the best purchase.

The only first-hand knowledge of the old diggings was obtained from JOHN ROCHE, of Crawfordsville, whose uncles (TOBINS) built and operated a bath- and boathouse along this part of Sugar Creek for many years on land bought from the ZELLERS in 1909. As a boy ROCHE lived in an old tar-paper shed for a few weeks in 1910 while his uncles were completing the cottage on their land. This building was the tool shed that had been built by the crinoid hunters to store their picks and shovels, and it was situated just west of the western ravine and close to the creek (Fig. 5). Just above the shed, two logs that were part of a footbridge across the ravine, are still in place. ROCHE can remember the fresh debris from quarrying that was still in evidence when he was a boy, and on visiting the locality, pointed out the west end of the quarried part of the bluff, just east of the footbridge, as the place where he remembers heaps of discarded rock. He also recalled that the ZELLERS, on disposing of the land, dynamited this old quarry site so that others would not dig there. The place is now overgrown, with little evidence of any diggings, except for the bluff profile, as mentioned above, and abundant crinoid columnals in the ravine below, which are weathering products of discarded debris in front of the bluff.

ROCHE recalled that the tool shed had a concrete

"cooler or refrigerator" in it. This may have been a tank or tub that was used by the collectors to wash and soften slabs of rock brought from the nearby quarry. This concrete tank is also remembered by RICHARD BANTA, author and longtime resident of Crawfordsville, who recalled that the sink lay along the edge of Sugar Creek for many years, although no trace of it can be found today.

In summary, the history of the Crawfordsville crinoid excavations serves to focus attention on the great burst of interest in fossils generated during the later part of the 19th century in the United States. This history also provides us with examples of the several attitudes and interests of men that led them to study fossils: the devoted, unselfish scientific interest of EDMUND and HORACE HOVEY; the quest for scientific recognition, through description of new species of fossils, by HALL, LYON, and WORTHEN; the hope of financial gain by BASSETT and ZELLER; the scientific importance of industrious and informed amateur paleontologists, such as the two COREYS; the alliance between paleontologists and professional collectors, as exemplified by BRAUN, BEACHLER, and SPRINGER; VAN DELOO and HALL; and BRADLEY and MARSH; and finally, of the desire to accumulate a large, unrivaled collection and carefully study it, by FRANK SPRINGER. So, the history of this locality displays for us the entire spectrum of desires and emotions that have always attracted men to fossils.

CRAWFORDSVILLE CRINOID BEDS

By N. GARY LANE and J. F. VAN SANT

EARLY STRATIGRAPHIC INTERPRETATIONS

Detailed study of rocks in the Crawfordsville region and correlation of them with beds in adjacent areas have never been made; however, because the crinoids are similar or identical to forms in known Keokuk beds, the Crawfordsville crinoid-bearing strata have been considered to be of this age. A detailed stratigraphical study of Montgomery County is not within the scope of the present investigation. The age of the rocks based on their crinoid fauna is discussed in a subsequent section.

Prior to 1931, the beds containing the crinoids were variously assigned to the Burlington (HOPKINS,

46, p. 49-52), Burlington and Keokuk (SIEBENTHAL, 127, p. 296-297; ASHLEY, 4, p. 66, 86-87), and most commonly to the Keokuk (e.g., 31, p. 317-318; THOMPSON, 143, p. 18; BEACHLER, 16, p. 65-70; NEWSOM, 114, p. 280-281; WELLER, 165, p. 353-368; CUMINGS, 33, p. 493-495; and others). STOCKDALE (140, p. 216) considered the rocks equivalent to his Edwardsville Formation of southern Indiana, but did not carry details of his studies into Montgomery County; his correlation is based merely on similar lithology and presence in the Edwardsville and Crawfordsville beds of similar-appearing crinoid bioherms. Since the time of STOCKDALE's study, the crinoid beds at Crawfordsville generally have been assigned to the Edwardsville Formation. In his paper on "Lower Mississip-

pian rocks of the east-central Interior," STOCKDALE (141, p. 229) again stated that "... they [crinoid beds] occupy an interval equivalent to the lower part of the Edwardsville division of Indiana and the Muldraugh unit of Kentucky." As with his previous study, this interpretation was based on indirect evidence.

Previous published rock sections at Corey's Bluff provide information on rock sequence. COLLETT's detailed measured section (31, p. 388) is as follows:

*Section of "Crawfordsville Beds" at Corey's Bluff,
by Collett (1876)*

	Ft.
Soft gray sandstone with crinoid stems and <i>Producti</i>	10.0
Shaly sandstone, without fossils	10.0
Ferruginous partings, <i>Pentremites</i>	0.5
Soft gray sandstone	5.5
Blue argillaceous sandstone	3.0
Blue siliceous clay shale, in places filled with crinoids and many other fossils, crinoid bed	4.5
Gray ferriferous sandstone	2.0
Blue shaly soapstone filled with fragmentary fossils, interrupted by an inclined dyke of limestone	25.0

BRAUN included a measured section of the beds at Corey's Bluff in his advertising circular for the Crawfordsville crinoids offered by him for sale. His section is as follows.

*Section of "Crawfordsville beds" at Corey's Bluff,
by Braun (?1881)*

	Ft.
Sandy soil	3.0
Soft sandstone, fossiliferous, containing decayed Crinoids and other fossils	10.0
A layer of fine-grained argillaceous sandrock of compact texture	0.9
Soft gray sandstone	8.0
Blue argillaceous sandstone	4.0
CRINOID BED, a blue siliceous clay shale containing scattered colonies of Crinoids and other fossils, the lower 5 feet containing mostly Lamellibranchs	10.0

BEACHLER (16, p. 408) published a similar but more generalized section from the same area in which he included all of the sandstone beds overlying the crinoid-bearing shale as a single unit. His section is as follows.

*Section of "Crawfordsville beds" at Corey's Bluff,
by Beachler (1889)*

	Ft.
Sandstone, containing fossils	30
Blue shale, crinoid beds	5
Limestone, encrinal	2
Blue shale, containing fossils	25

STOCKDALE (140, p. 216), who published the most recent geologic section, assigned the various units to his Edwardsville, Floyds Knob, and Carwood formations as follows.

*Section of "Crawfordsville beds" at Corey's Bluff,
by Stockdale (1931)*

	Ft.
Edwardsville Formation	
Covered	
Sandstone, shaly, soft, with uneven sandstone ledges projecting as ribs; abundant bryozoans and crinoids	10
Edwardsville and Floyds Knob Formations	
Limestone, crinoidal, as irregular thin lenses, intercalated in a mass of blue shale which comprises bulk of interval; many crinoids in shale	20
Carwood Formation	
Shale, sandy, brittle, blue to drab, with abundant worm marks	---

Comparison of the above-reported sections indicates that BRAUN's and COLLETT's sections are quite similar except that BRAUN did not include in his section lowest exposed beds (25 feet thick according to COLLETT) from creek level up to the crinoid bed. BEACHLER and COLLETT reported an aggregate thickness of 62 and 60.5 feet, respectively, whereas STOCKDALE reported only 30 feet of rock, which may indicate that much of the upper part of the bluff where STOCKDALE measured his section had been covered since the time of the earlier studies. The "crinoid bed" itself presumably was about 27 feet above creek level, assuming that both BEACHLER's and COLLETT's sections began at creek level. This is in close agreement with observations of the junior author of this report, who found six well-preserved crinoid crowns during the summer of 1963 in an exposure in the side of the eastern ravine bounding the old quarry sites (Fig. 5). These crowns were obtained within a stratigraphic interval of 3.5 feet that began 24 feet stratigraphically above lowest exposed beds. The lower 24 feet of strata consists of interbedded soft blue gray siltstones containing abundant disarticulated crinoid parts, and lenticular, platy, crinoidal limestone beds, 3 inches to 1 foot thick.

The interval from which the crinoid crowns were obtained consists of blocky to thin-bedded, dark blue gray, micaceous siltstone in beds 2 to 6 inches thick. Interbedded with the siltstone are lenticular masses of weakly cemented, iron-stained, crinoid debris 1 to 2 inches thick and 6 inches to 1 foot long. All of the crowns were obtained from the siltstone, not from the lenses of disarticulated crinoid pieces.

Information on the actual beds containing crinoids is also contradictory. The thickness of these beds was reported by HOVEY (47) to be generally about 2 feet, but in places he reported that they thinned to 6 or 8 inches; COLLETT (31) stated that the beds were 4 feet, 6 inches; BRAUN indicated that the crinoid beds were 10 feet thick; BEACHLER in 1889 (16) reported them to be 5 feet, but in 1892 he stated they were more

than 10 feet; STOCKDALE (140) described the blue shale unit as comprising the bulk of the interval, which he reported to be 20 feet thick. These differences (from 8 inches to nearly 20 feet) presumably are explainable by location of sections reported by the various authors in slightly different parts of Corey's Bluff. Thus, just as information concerning stratigraphy of the beds is not available, the thickness and distribution of the crinoid-bearing beds is not precisely known. As discussed below, the type of rock that forms the matrix has also been variously described.

BEACHLER (17, p. 95) suggested that at least two different levels, each characterized by different crinoid genera, were present. According to his observations, the lower one, from water level to about 10 feet above Sugar Creek at his quarry site, was characterized by inadunates, especially *Cyathocrinites*, *Poteriocrinites*, and *Barycrinus*. Above this level, camerates and flexibles were dominant, represented by *Onychocrinus*, *Forbesiocrinus* (= *Taxocrinus*), *Gilbertsocrinus*, and *Platycrinites*. BEACHLER's differentiation of genera is not substantiated by our study of fossils preserved on slabs and associated together on pieces of matrix. As shown by slabs seen at Wabash College and others reported by LANE (66), all three groups of crinoids occur together.

UPPER BORDEN GROUP IN MONTGOMERY COUNTY, INDIANA

GENERAL DESCRIPTION

The bedrock geology of Montgomery County includes rocks of the upper part of the Borden Group (Osagian), a small outlier of Harrodsburg Limestone (Meramecian) in the southern part, and Lower Pennsylvanian sediments of Pottsville age along the southwestern border of the county. Exposures are limited to stream edge and artificial road and quarry outcrops because most of the surface is covered by thick deposits of Pleistocene drift and Recent alluvium. The Crawfordsville crinoid beds are restricted to upper Borden Group rocks, and only this stratigraphic interval will be discussed here.

The Corey's Bluff crinoid locality, as well as other crinoid-yielding beds in the county, are all judged to be in the upper part of the Borden Group. Twenty-two test wells drilled in the southeastern part of Montgomery County, south of New Ross and east of Ladoga, penetrate between 575 and 383 (average, 482) feet of Borden and Rockford Limestone rocks combined (Indiana Geol. Survey Petroleum Explor.

Map 20A). The Borden is next below Pleistocene deposits in this area and presumably higher beds of the group have been removed by erosion. Because the Rockford Limestone is thin, generally less than 3 feet, and the Borden Group ranges from 400 to 765 feet in thickness (STOCKDALE, 140), Borden rocks at or near the surface in southeastern Montgomery County are in the upper part of the group.

Four other wells in the county (Fig. 8) in which the elevation of the top of the New Albany Shale below the Borden is known, penetrate 448 to 815 feet of bedrock (including Harrodsburg-Salem rocks in the well with the greatest thickness) before reaching the New Albany. This means that a considerable thickness of Borden rocks, possibly 400 to 500 feet, is present in the subsurface across the county. All surface exposures of the Borden Group in Montgomery County, and therefore all crinoid-yielding beds, can be considered to be in the upper part of the group, even though the exact stratigraphic relations of all exposed beds may not be known with certainty.

In this study two aspects of Borden stratigraphy in the county are important: (1) the stratigraphic relations of the Crawfordsville crinoid beds to other fossiliferous Borden rocks that have yielded crinoids; and (2) the relationship of crinoidal deposits to close by, laterally contiguous, noncrinoid-yielding rocks.

In addition to Corey's Bluff, crinoids were obtained by early collectors at several other localities. All of these places can be reasonably well located today and all consist of interbedded crinoidal siltstones and subordinate limestones that contain abundant isolated crinoid parts and other fossils. The most famous site, which yielded most specimens other than those from Corey's Bluff, was along Indian Creek in the southwestern part of the county (Fig. 8), and crinoids from this area were labelled "Indian Creek" in the old collections. Presumably there were several early collecting spots along Indian Creek. COLLETT (31) recorded crinoidal limestones that are still in evidence at the mouth of the creek, and the junior author of this report collected several complete crowns from the stream bed of a small tributary to Indian Creek about a quarter mile upstream from the mouth. The most prolific locality along the creek was discovered by BEACHLER in 1886 and quarried by him in 1887 and by BRAUN in 1907 for SPRINGER. On SPRINGER's copy of COLLETT's map of the county, BEACHLER's locality was originally placed a quarter mile upstream from the mouth of Indian Creek (S $\frac{1}{2}$ Sec. 1, T. 17N, R. 6W.), indicated as "BEACHLER's crinoid find," but this was later scratched out and a locality was marked in the center of the south half of Sec. 8, T. 17N., R. 5W., and was indicated in SPRINGER's handwriting as "crinoids

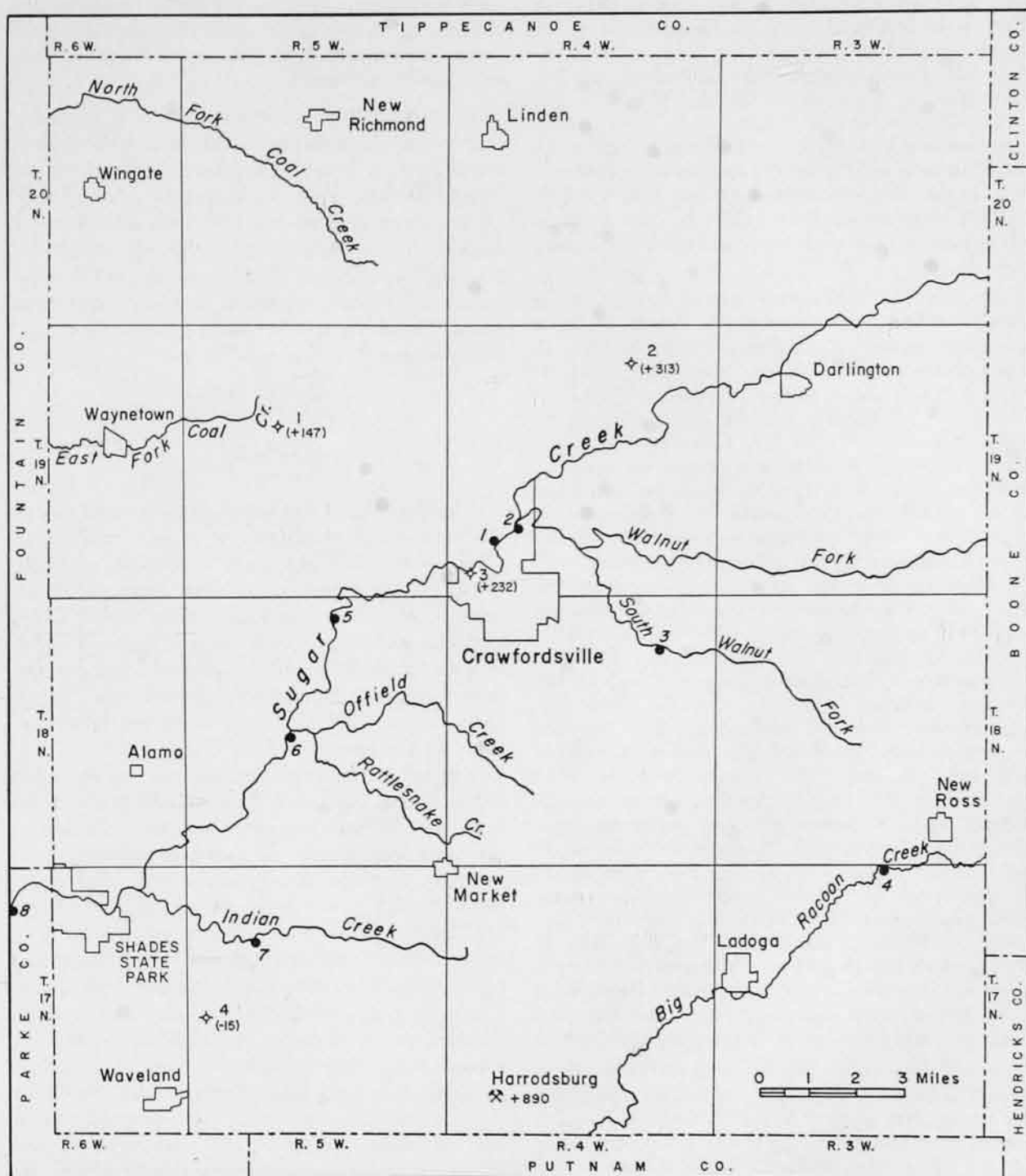


FIGURE 8. Map of Montgomery County, Indiana showing locations of crinoid-bearing Borden rocks in the county, and wells that furnished data for regional dip determinations. Crinoid localities are: 1) Corey's Bluff, 2) County Farm, 3) Walnut Fork, 4) New Ross, 5) Country Club Road, 6) mouth of Offield Creek, 7) Indian Creek, and 8) Scott's Eagle Mill. Numbers in parentheses beside each well denote elevation of top of the New Albany Shale.

BEACHLER." On BEACHLER's personal copy of COLLETT's map, in the Springer Library, the Indian Creek locality is designated in the center of the SE $\frac{1}{4}$ of Sec. 8. In SPRINGER's notebook in the National Museum (p. 202, "Localities in Montgomery County, Indiana"), the Indian Creek occurrence is listed as 14 miles west of Crawfordsville in Sec. 8, as "BEACHLER's great nest." This locality is actually 9 miles southwest of Crawfordsville. In this notebook SPRINGER also lists another collecting site along Indian Creek which he calls a "sandy magnesian layer 100 yards below and a few feet higher" than the first.

COLLETT (31) listed other crinoid localities, or at least fossil beds similar to those at Crawfordsville, at the mouth of Black Creek (SE $\frac{1}{4}$ Sec. 34, T. 19N., R. 5W.), at the mouth of Offield Creek (S $\frac{1}{2}$ Sec. 16, T. 18N., R. 5W.), and in a brook southeast of Troutman's Mill (now Yountsville), near the center of the north half of Sec. 3, T. 18N., R. 5W. Crinoidal siltstone and limestone can still be observed at or near the latter two localities, but not at the first. No record has been found of any crinoid crowns collected at any of these localities and if they were, specimens were probably labelled "near Crawfordsville," or "Montgomery County."

There is evidence that crinoids were collected at still other places in the county. Crinoidal siltstones are exposed along the south branch of Walnut Ford (NE $\frac{1}{4}$ Sec. 11, T. 18N., R. 4W.), called the Dice locality in early notebooks, four miles southeast of Crawfordsville. SPRINGER recorded in his notebook that *Barycrinus*, *Agaricocrinus*, and *Alloprosallocrinus* occur here and that the beds are "evidently higher than the Crawfordsville bed." BEACHLER (17) also recorded *Dorycrinus gouldi* from this locality. Another locality was the County Farm, a quarter mile east and across Sugar Creek from Corey's Bluff. BEACHLER also collected crinoids from a locality south of New Ross (then Baker) in the eastern part of the county. SPRINGER reported "*Alloprosallocrinus* (*vide* Beachler)" from this place along Big Raccoon Creek (NE $\frac{1}{4}$ Sec. 3, T. 17N., R. 3W.), which was the site of a lime quarry for several years and is now owned by the New Ross Conservation Club. The quarry pits have been flooded and only about 4 feet of outcrop above water level can now be observed.

Finally, one other locality in northeastern Parke County, adjacent to the southwestern edge of Montgomery County, was reported to yield crinoids. This locality is marked on BEACHLER's copy of COLLETT's map as being at the former site of Scott's Eagle Mills, which is recorded on the map, and is in SPRINGER's notebook as "Scott's Mill same as Indian Creek." The mill has long since vanished, but comparison of COLLETT's map with a modern topographic map of the area (Alamo quadrangle) reveals that the mill probably was situated in the north half of Sec. 8, T. 17N., R. 6W., along Sugar Creek. This locality is important because it was at this

place that BEACHLER (17) asserted that he found elements of both the Indian Creek and Crawfordsville crinoid faunas in superposition, with the Indian Creek fossils in stratigraphically lower beds.

BEACHLER (17) was the only person to attempt a stratigraphic synthesis of these localities in the county, and to arrange them in a sequence. This scheme, accepted by paleontologists describing the crinoids (WACHSMUTH & SPRINGER, 159; SPRINGER, 136) was that the Crawfordsville beds were younger than those at any of the other places in the county, and that the Indian Creek beds represented older crinoid-yielding strata. The stratigraphic sequence given by BEACHLER, with youngest at the top, is as follows.

Sequence of Beds

Crawfordsville beds
Indian Creek
Walnut Fork
New Ross

This hypothesis was based on three lines of evidence: presence or absence at certain localities of crinoid genera that range above or below into younger or older rocks respectively in other areas; the occurrence of what BEACHLER judged to be typical Crawfordsville and Indian Creek crinoids in superposition at Scott's Eagle Mill; and similarity of lithologies and their sequence in Montgomery County, with Osagian rocks in the standard section along the Mississippi River on the west side of the Illinois basin.

Reliance of lithologic sequence on the two sides of the Illinois basin as a basis for stratigraphic relations is a spurious argument and too uncertain to place any weight today on such a comparison.

Study of the rocks exposed in the bluff along Sugar Creek opposite the former site of Scott's Eagle Mill by the junior author in the summer of 1963 failed to reveal any criteria, faunal or lithologic, that could affirm BEACHLER's contention that both Indian Creek and Crawfordsville faunas occur here in superposition. About 40 feet of typical Borden siltstone is exposed in the bluff below a disconformity with massive, conglomeratic basal Pennsylvanian sandstone above. The only fossils that were detected were a few specimens of *Spirifer* and rare, small crinoid columnals, with no indication that there would be any likelihood of finding complete crinoid cups, or even cup plates. The outcrops may have changed enough during the last 70 years that BEACHLER's evidence has been obliterated, but we do not feel that his hypothesis can be supported in the light of re-examination of the locality.

The Indian Creek and Walnut Fork beds were judged to be older because they yielded specimens of *Agaricocrinus*, *Dorycrinus*, and *Woodocrinus* that are rare or absent at Corey's Bluff and that range down into older rocks. Although there are differences in the crinoid faunas of this sort, many species are in common and all Montgomery County crinoid beds are close to the same age. As indicated by review of systematics in this study, many species are considered to be synonyms of previously described species, and a similar study of the Indian Creek and other faunas in the county would also probably reach the same conclusion. Thus, comparison of the crinoids from these localities must await review of all faunas.

The best solution to the problem of stratigraphic relations would be obtained by tracing various forms from outcrop to outcrop and by recognition of suitable marker beds from Corey's Bluff to Indian Creek and other fossil localities. Unfortunately this cannot be done. There are no reliable key beds that can be used in this way, with any certainty that matching up of beds from one exposure to another is correct. Most outcrops of Borden rocks are small, discontinuous, and consist of massive, unfossiliferous siltstones that exhibit few distinct bedding surfaces or vertical lithologic changes that can be traced more than a few hundred feet. The abrupt facies changes that occur between crinoid-bearing and unfossiliferous siltstones (see below) are compelling evidence that we cannot rely on lithologic criteria for demonstration of lateral equivalence for any distance greater than a mile or two, and are a cogent argument against making lithologic comparison with same-age rocks on the west side of the Illinois basin, as attempted by BEACHLER.

Another approach is to determine the regional strike and dip of Borden rocks in the county, and with known geographic and altitudinal position of each fossil locality, to determine their relative stratigraphic placement, based on regional tilting. Using the four wells shown in Fig. 8, the only wells in the county for which sufficient records are available and which are not affected by local structural complications, the regional dip, determined by three-point graphic methods with the top of the New Albany Shale as a reference datum, is as follows. Using wells 1, 2, and 3 in Fig. 8, the strike is N. 5°W. and the dip 21 feet per mile west; wells 1, 2, and 4 yield a strike of N. 25°W. and dip of 22 feet per mile; and wells, 1, 3, and 4 a strike of N. 18°W. and a dip of 28 feet per mile. Wells 2, 3, and 4 are too nearly in

a straight line to use for dip determination. The average strike and dip determined from these wells, then, is N. 16°W. and 24 feet per mile, and these figures are of the same order as regional strikes and dips farther south in Indiana in the Borden determined by STOCKDALE (140). These average figures have then been used to determine the relative stratigraphic position of beds at the known fossil localities, whose geographic position and elevation could be accurately determined from up-to-date topographic maps of the county.

Using this method it turns out that the Crawfordsville beds should be about 225 feet stratigraphically below those at Indian Creek rather than above them, as postulated by earlier writers. In order for the Indian Creek beds to be at the same or a lower stratigraphic level as the beds at Corey's Bluff, there would have to be a regional dip to the east, instead of to the west. The fossil beds at New Ross and along the south branch of Walnut Fork were determined to be about 25 and 15 feet, respectively, above the Crawfordsville beds. These differences are probably within the margins of error of this method, and these three localities are probably quite close to the same stratigraphic position, and all are well below the Indian Creek occurrence. That the Indian Creek locality is indeed high in the Borden Group is partly confirmed by presence of northernmost surface exposures of Harrodsburg Limestone (next above the Borden Group) about five miles southeast of the Indian Creek locality at an elevation only 145 feet higher (Fig. 8). Using the same average strike and dip as above, this would place the Indian Creek beds only 45 feet stratigraphically below the base of the Harrodsburg.

If this interpretation is correct, it conflicts with available faunal evidence from these localities, especially between the two best known faunas—those at Indian Creek and Crawfordsville. This faunal discrepancy could be due to somewhat different biofacies at the two localities; the Indian Creek beds are somewhat less limy and more sandy than at Crawfordsville. The lithologic differences may reflect subtle variations in near contemporaneous environments that led to establishment of colonies of crinoids and other fossils with somewhat different taxonomic composition in response to such environmental influence.

In summary, the chronologic relations of the various crinoid localities within the county must be considered an unresolved problem, and the older interpretation should be re-evaluated in the light of

this new evidence. A critical review of the taxonomic differences between the Crawfordsville and Indian Creek faunas must await careful study and revision of the Indian Creek crinoids, which has not yet been undertaken.

FACIES CHANGES

The Crawfordsville crinoid beds, as well as other crinoid-yielding strata in Montgomery County, show abrupt facies change with laterally contiguous, unfossiliferous Borden rocks. This relationship can be observed in various places.

COREY'S BLUFF

The body of crinoid-bearing strata that comprises the lower 25 to 30 feet of beds at the old quarry sites passes laterally into thin-bedded unfossiliferous siltstones within a few feet along the west edge of the fossil deposits. Strata exposed in the small ravine at the west edge of the quarry sites (Fig. 4) lack crinoids and other fossils.

COUNTY FARM

Along the bluff at the confluence of Sugar Creek and Walnut Fork, below the Montgomery County Farm, the same relations as above can be observed. Borden rocks along the northern part of this bluff are sparsely fossiliferous, containing rare specimens of *Chonetes* and fenestrate bryozoan fronds. South along the bluff one first encounters abundant fossils in a 10-inch thick limestone bed composed of large and small crinoid stems, *Platyceras*, and other fossils at low-water creek level. This bed is lenticular, thins to a feather edge, and then thickens again for an exposed distance of 150 feet. Where the resistant limestone ledge is absent it is replaced laterally by clayey siltstone containing abundant disarticulated crinoid stems and cup plates. At the northern limit of this lowest limestone, rocks above it are unfossiliferous siltstones, but at the southern limit of exposure, just before all bedrock is covered by Pleistocene drift, fossiliferous limestone beds and thin-bedded, crinoidal siltstones are exposed from creek level up a small ravine in the hog lot behind the county farm for a vertical distance of 65 feet. One lenticular limestone bed 30 feet above creek level can be traced 25 feet north of the ravine before it is covered by alluvium that drapes the top of the bluff, but is absent another 50 feet northward where bedrock is exposed. Several outcrops north of this bluff, such as shale pits one-half mile north and one mile northeast, as well as stream bank exposures along Walnut Fork, are all unfossiliferous, thick-bedded siltstones. It is possible that the county farm beds and those at Corey's Bluff are part of the same continuous fossiliferous body of rock. Both sequences have a resistant limestone ledge at creek level and are less than one-eighth mile apart.

Lack of exposures along Sugar Creek between the two areas is responsible for the uncertainty. If the two sections are part of a continuous body of fossiliferous rock, it clearly was thicker near the northeastern exposed limit at the county farm (65 feet) than at Corey's Bluff (30 feet), and is a little less than a quarter mile in maximum exposed dimension.

COUNTRY CLUB ROAD

Exposures of Borden rocks in road cuts along the Country Club road, just north of Indiana State highway 32, and natural exposures along Sugar Creek 300 yards farther north, are part of another crinoidal lens of rock (Fig. 8). Fossiliferous strata have a maximum exposed thickness of 55 feet and are overlain by 12 feet of unfossiliferous massive sandy siltstone. Lenses of crinoidal limestone are present about three and 45 feet above creek level, the rest of the deposit consisting of soft calcareous siltstone. Several camerate crinoid cups were collected by LANE during the summer of 1963 in the upper part of this deposit. Exposures along Sugar Creek north of this lens and from base level up Mill Creek tributary a quarter-mile to the south, are typical sparingly fossiliferous siltstones in which a few sponges, trilobites, bryozoans, and brachiopods can be found, but which almost lack any crinoid remains. This fossiliferous lens then is about 55 feet thick and 1,300 feet long in its exposed dimensions.

WALNUT FORK

Creek bank exposures along the south side of South Walnut Fork (Fig. 8) also show this abrupt facies change. From the bridge over the creek outcrops to the east, and for 75 feet below the bridge to the west, are unfossiliferous siltstones. Bedrock outcrops are interrupted west of this point for about 55 feet by a large Pleistocene gravel deposit. Next observed Borden beds to the west are highly fossiliferous crinoidal siltstones and subordinate, thin lenses of hard crinoidal limestone discontinuously exposed along the creek for about 800 feet. The maximum exposed thickness is 30 feet. The facies change occurs here then within 55 feet laterally. In the easternmost fossiliferous outcrops there are several limestone lenses, each 4 or 5 feet wide and up to 18 inches thick. The creek has eroded less resistant siltstone surrounding the limestone, so that each lens projects out into the creek. The lenses are elongate in a northwest-southeast direction, so they have distinct orientation in the rock. Their upper surfaces are convex, with siltstone warped over the top of each one. They appear to be "windrows" of crinoidal and other invertebrate debris accumulated on the sea floor by currents. This is the only locality where this feature was observed.

OFFIELD CREEK

Along the east bank of Sugar Creek just south of the mouth of Offield Creek a small accumulation of crinoid-

bearing rocks occurs. This is a composite lens made up of several lenticular beds of crinoidal limestone up to 18 inches thick and thin, interbedded crinoidal siltstones. The entire deposit is 150 feet long and 20 feet thick at the center, thinning to a feather edge within a few feet. Siltstone 4 feet thick and laterally contiguous to the lens contains abundant crinoid stems and cup plates but no complete cups were observed. A few feet north and south along the creek fossiliferous siltstone is replaced by unfossiliferous rocks.

CONCLUSIONS

Synthesis of data cited for the localities described leads to conclusions that the fossiliferous, crinoidal siltstones and limestones are relatively small bodies of rock, not more than one-quarter mile in maximum observed lateral dimension nor greater than 65 feet thick; that crinoidal limestone is a subordinate lithologic type, and fossiliferous siltstones are more common; that facies change between the crinoidal lenses of rock and surrounding unfossiliferous siltstone is abrupt, commonly occurring within a few tens of feet laterally, where it can be observed closely; and that fossiliferous rocks thin toward the edges of the lenses, with greatest lateral extent in lowest exposed beds.

Circumscribed accumulations of crinoid-bearing rocks in the upper Borden Group were first reported by STOCKDALE (1931), who studied several such deposits in west-central Indiana, south of Montgomery County. He recognized seven bioherms (in the sense of CUMINGS, 1930) in Monroe, Brown, and Morgan counties in his Edwardsville Formation, uppermost unit in the Borden. These bioherms occur in an area about 30 miles long north-south, and eight miles wide, east-west. STOCKDALE realized that these more southerly deposits were similar to the Crawfordsville crinoid beds, and largely on this basis, correlated the latter with his Edwardsville Formation.

Crinoid beds of the upper Borden in Montgomery County are about 60 miles northwest of those studied by STOCKDALE, and in both instances abrupt facies changes may be observed between abundantly fossiliferous crinoidal limestone and siltstone, and surrounding unfossiliferous siltstone. Where exposures permit close study, the deposits in each case seem to have maximum lateral extent in lower beds, becoming gradually restricted areally in higher beds. Limestones consist of crinoidal debris, including large columnals up to an inch in diameter, that is conspicuously larger, more abundant, and in a more disarticulated state, than in interbedded siltstones.

The southern bioherms differ from those in Montgomery County in that the former are more exten-

sive deposits, commonly one or two miles in exposed extent; are generally 60 or 70 feet thick; and include proportionately more limestone and less siltstone. Especially near the centers of the southern deposits, they consist predominately of crinoidal limestone (STOCKDALE, 1931, pl. 6). The bioherms to the south have not yielded crinoid faunas comparable to those in Montgomery County, and there are few records of any crinoid cups or crowns having been collected from them.

The carbonate petrology of one of the southern bioherms (near Stobo, Indiana) has been studied recently by CAROZZI & SODERMAN (23) who divided the bioherms and surrounding rocks into seven microfacies. These authors postulated that "bioaccumulated crinoidal limestone," the dominant microfacies in the Stobo deposit, represents "time of optimum conditions for the development of crinoids," and that thin beds of noncrinoid-bearing calcilitite, generally next above the crinoidal limestones, were generated by algal dust accumulations on the sea floor that were inimical to the crinoid colonies. They also judged that the crinoids flourished in a local depression on the sea floor because "establishment of a crinoid colony requires an undisturbed substratum." The rock at Crawfordsville, that has yielded the majority of complete crinoid specimens for which the locality is famous, apparently is not identical to any microfacies described by CAROZZI & SODERMAN, which may explain why few crinoid calyces have ever been found in the Stobo or other nearby crinoid deposits. The Crawfordsville crinoids occur in a siltstone (see below), not a calcilitite or crinoidal limestone, even though the above authors mention that crinoid stems a foot or more in length are occasionally found in the calcilitite. Siltstones that they describe contain only scattered crinoid fragments that commonly are abraded.

Considering the differences in size and gross lithologic composition, and the geographic separation between the Stobo deposit and those in Montgomery County, the environmental interpretation given by CAROZZI & SODERMAN may not apply to the more northern deposits, even though they are all within the same stratigraphic interval. Until comparable petrologic studies have been made of one or more of the Montgomery County crinoidal deposits, judgment on a common, or dissimilar, mode of origin would be speculative. We can point out, however, that observed gross differences in the crinoidal accumulations in the two areas may be partly a function of their differing geographic position relative to the general paleo-

geographic distribution of land, sea, and major sources of terrigenous sediments during Osagian time in Indiana. At least, SWANN (142) has shown that there was a major source of terrigenous clastics (his Michigan River) north of Indiana, and therefore closer to the Montgomery County deposits, during somewhat later Mississippian time.

LITHOLOGY OF CRINOID-BEARING BEDS

The rock in which the Crawfordsville crinoids are preserved has been variously described by previous authors. HOVEY (47) described it as a calcareous shale or sandstone; COLLETT (31) referred to it as a blue siliceous clay shale; and BEACHLER (16) and STOCKDALE (140) described the rock as a blue shale. More recently, LANE (66) described the matrix as a "uniformly fine-grained, dark blue-gray argillaceous limestone." Although a detailed petrological study of the sediments is not within the scope of the present study, the different interpretations of the character of the matrix led us to examine the rock somewhat more closely. Five random rock samples were chipped from slabs belonging to the Hall, Gurley, and Faber collections (University of Chicago, Walker Museum) and results of various tests indicate that the matrix is entirely different from that indicated in previous reports. Five random samples can hardly be expected to show the true nature of the matrix, however.

Results of size analysis, tests of carbonate content, X-ray analysis of clay, and microscopic study of hand specimens indicate that the matrix consists of a dark blue-gray siltstone—or probably a mudstone (as defined by INGRAM in 1953 for materials of massive character in which the proportion of clay and silt is not known). The rock lacks fissility and is not composed predominantly of clay-size particles; therefore, it should not be referred to as a shale. The only sand-size particles found were fossil fragments consisting largely of crinoid and bryozoan fragments, and thus the matrix cannot properly be called a sandstone. Likewise, the term limestone is unacceptable because the amount of calcium carbonate is relatively low, ranging from 3.4 to 18 per cent in samples tested. Most, if not all of the calcium carbonate present in the rock represents fossil fragments. Results of X-ray analysis indicate that the clay present in the rock is predominantly illite and chlorite.

Four characteristics of the matrix are particularly noticeable. (1) Fossil debris is sparse on most surfaces, but in some places a concentration of fragments seems to occur. (2) Abundant occurrence of pyrite, which

is discussed more fully in the next section, is very common on fossils, but seemingly it is rare in the matrix; however, very small dispersed particles of pyrite can be observed microscopically on nearly all samples of rock. (3) Yellow and red color, caused by oxidized pyrite, is common on surfaces containing a concentration of fossil fragments and on many specimens. More rarely a green color, suggesting oxidation of ferrous iron, can be observed. (4) The matrix is very hard but examination of many prepared crinoid specimens and information given in early reports of the crinoid locality indicate that when the rock was first exposed the matrix was soft and easily "worked." Most specimens, which have been prepared by collectors, appear as if the surface of the matrix was easily carved and smoothed with a knife. It is not known whether the hardening was caused by loss of water on exposure to air or by some chemical change that has occurred. However, the former seems most probable and samples that are soaked in water for prolonged periods become soft and easily workable. Probably the hardening is caused in large part by desiccation of clay-size particles in the matrix.

The good preservation of the Crawfordsville crinoid fauna has been repeatedly mentioned in the literature; however, the presence of pyrite in most specimens has resulted in destruction of many structural details. Most commonly partial pyritization of fossils has resulted, but some are completely pyritized and others are not replaced at all. The factors causing pyritization and those responsible for the differential amount of replacement cannot be satisfactorily explained by present knowledge of the crinoid-bearing beds. Comparatively little is known about distribution of the fossils in relation to degrees of pyritization. Seemingly, the pyrite is not restricted to zones (e.g., lower layers of crinoid colony, etc.) because many completely pyritized fossils occur on the same slabs with unreplaced fossils, commonly only a few millimeters apart.

The occurrence of pyrite seems best explained by local reduction caused by concentration of organic matter. This would explain why most pyrite is confined to the specimens but it does not satisfactorily explain why some specimens are differentially pyritized.

COMPOSITION AND AGE OF CRAWFORDSVILLE CRINOID FAUNA

Re-examination of crinoids in this study has resulted in recognition of 55 valid species. Previously,

BASSLER & MOODEY (9, p. 92-94) listed 83 species reported from the Crawfordsville beds, but as already mentioned, many of these have been found to be synonyms and many other reported occurrences could not be confirmed from published descriptions. The presence of identical species in Keokuk rocks at the type locality in Iowa, in Montgomery County, Indiana, and at localities in Kentucky and Tennessee indicates an extremely wide distribution for some forms and supports judgment that the Crawfordsville fauna is of Keokuk age.

Inadunates are the most common group of Crawfordsville crinoids in number of species. The disparids are represented by single known species of *Eucatillocrinus* (Allagecrinidae), *Halysiocrinus* (Calceocrinidae), and *Synbathocrinus* (Synbathocrinidae). Specimens of *S. swallowi* are the most abundant disparids known from Crawfordsville, even though the species is represented by only 13 known specimens. Curiously, this form has not been reported previously from this locality.

Thirty species assigned to the order Cladida were studied from material available for the systematic investigation. These represent 16 genera, which in number of individuals are very unevenly distributed. Some species are represented by more than 100 known specimens whereas others are recognized on the basis of only a single specimen. The barycrinids (2 genera, 5 species), cyathocrinitids (1 genus, 5 species), pachylocrinids (2 genera, 5 species), and scytalocrinids (4 genera, 8 species) are most abundant in both numbers of specimens and species. The ampheristocrinids, erisocrinids, glossocrinids, poterocrinitids, and zeacrinids are each represented by a single species, none of which are common. In addition, two cladid genera (*Corythocrinus*, *Goniocrinus*) are not assigned to a family and each is known from only a few specimens.

Only species of a single flexible family, the taxocrinids, occur in the crinoid beds; however, earlier studies stated that *Forbesiocrinus* (a sagenocrinitid) also was reported. Considerable nomenclatural confusion and many misidentifications have been responsible for this improper conclusion. *Taxocrinus colletti* is one of the most abundant species in the beds, and although much more rare, specimens of *Onychocrinus exculptus* and *O. ramulosus* form a conspicuous aspect of the fauna. *Parichthyocrinus crawfordsvillensis* is known from only two specimens.

Six camerate families, represented by 13 genera and 17 species were present in material available for study.

The dicyclic forms are all assigned to a single species of *Gilbertsocrinus* and in terms of individuals it was seemingly moderately abundant. The monocyclic camerates are very unevenly distributed. The Actinocrinitidae and Platycrinidae are each represented by a single species, but specimens of *Platycrinites hemisphericus* are extremely common. Two species assigned to *Agaricocrinus* were available for study, both of which are very rare. The dichocrinid genera, *Dichocrinus*, *Camptocrinus*, and *Paradichocrinus* are represented by 5 species, of which only *P. polydactylus* could be considered common. The most diverse group of camerates found in the Crawfordsville beds comprises the batocrinids. *Abatocrinus*, *Alloprosallocrinus*, *Eretmocrinus*, *Macrocrinus*, and *Uperocrinus* are each known from single species in these beds, but 3 forms of *Dizygocrinus* have been described. Only *Abatocrinus grandis* and *D. indianaensis* are abundant; other species being known from just a few specimens.

Of the total 55 valid species recognized in this study, 25 are known only from Crawfordsville beds. Eighteen are common to both Crawfordsville and Indian Creek and five are known to have occurred at Crawfordsville and other localities in Indiana (e.g., near Canton). Study of species found in the Crawfordsville beds and areas in the Upper Mississippi Valley (Missouri, Illinois, Iowa) indicates that only eight forms are common to both regions. Mostly these are rather generalized species, such as *Synbathocrinus swallowi* and *Scytalocrinus robustus*. More commonly species found at Crawfordsville are similar to those from the Fort Payne Chert of Kentucky and Tennessee.

Lithologically, Keokuk limestones of the type area consist largely of massive, blue-gray limestones with abundant crinoid fragments in the rock. The limestone units are commonly interbedded with soft, blue-gray shales that attain considerable thickness in the upper part. Almost invariably the well-preserved crinoid thecas are imbedded in the shales. Commonly these crinoid remains are abundant, but little evidence of a colonial habit has been found in the type area. Equivalent beds of Indiana, Kentucky and Tennessee (Borden Group, Fort Payne Chert) are lithologically quite distinct. As discussed by STOCKDALE (141), units within these groups are marked by rapid change in facies, and as mentioned previously, consist generally of thick sequences of blue-gray shales, silts, and sands with only minor amounts of carbonate rock in the form of lenses. In addition to difference in gross

lithologies, the areas on opposite sides of the Illinois Basin also differ in mode of occurrence of the faunas. In Indiana, Kentucky, and Tennessee, large concentrations of colonies or bioherms are characteristic. The crinoid beds at Crawfordsville represent one of these local concentrations.

Analysis of the Crawfordsville fauna, especially the crinoids, yields considerable information concerning its age. Although only a few species seem to have a wide geographical distribution, most forms found at Crawfordsville are very closely related to species in Keokuk rocks at the type locality; some appear to be direct descendants or possibly ecologic variants. At any rate, as a group they are unquestionably more closely related to known Keokuk species than to either Burlington or Meramec forms.

The most important group of crinoids for age determination of the Crawfordsville fauna are the camerates. As an assemblage, they seem to be more specialized than other forms, and genera, as well as most species, are more narrowly restricted stratigraphically. In particular, the batocrinids are very significant and specimens are commonly represented by an extraordinarily large number of individuals. *Dizygocrinus* and *Alloprosallocrinus* are restricted to the Keokuk, and both occur in the Crawfordsville beds. The former is represented by profuse numbers of individuals. Generally, Keokuk batocrinids differ from geologically older forms in being more robust, as well as strongly ornamented by nodes and radial ridges, and commonly some forms have more numerous arms. Mostly these features represent terminating lines of evolutionary trends that began in Burlington time. None of the six genera present in the Crawfordsville beds have been reported from younger strata.

The actinocrinitids are rare in the Crawfordsville beds, only one species of *Actinocrinites* being known. It has large ponderous arms and an uncommonly large theca, similar to the Keokuk species, *A. lowei*. The dichocrinids, a rather unspecialized group of camerates, are represented by three genera. Specimens of *Dichocrinus* resemble other Keokuk species from the Upper Mississippi Valley, but species of *Paradichocrinus* are known only from Montgomery County, Indiana. Specimens of *Camptocrinus* are rare at Crawfordsville and none were available for study. *Agaricocrinus*, a coelocrinid, is represented by two species at Crawfordsville. *A. americanus* is also known from Keokuk rocks in Missouri, Illinois, and Iowa, and *A. splendens* occurs in Washington and

Montgomery Counties, Indiana. *Platycrinites hemisphericus* (Platycrinitidae) somewhat more closely resembles Upper Burlington forms of the genus than other known Keokuk species, but it differs from older forms by having a more bowl-shaped dorsal cup, less robust arms, and a flatter tegmen.

Inadunate crinoids are common in rocks of Osagian age (and throughout the Mississippian), but in general they seem less specialized than camerates and most groups have a rather long stratigraphic range. They are much more useful for age determination in younger strata and in Meramecian and Chesteran time are the most abundant group of crinoids known. Few genera are restricted to the Keokuk and only *Abrotocrinus*, *Cydrocrinus*, *Pellecrinus*, and *Scytalocrinus*, among forms found at Crawfordsville, particularly characterize beds of Keokuk age. Other genera restricted to the Keokuk are known only from Indiana (e.g., *Eucatilocrinus*). Comparison of Crawfordsville species with those occurring in the type area of the Keokuk, however, indicates that these forms are closely related. Similarities with species from the Fort Payne Chert in Kentucky and Tennessee are particularly noticeable. Within many inadunate groups major trends that developed in older Mississippian species can be traced to features found in Crawfordsville species and other crinoids of Keokuk age. Thus, on the basis of considerations mentioned above, the crinoid fauna from Crawfordsville unquestionably is equivalent to those found in Keokuk rocks of the Upper Mississippi Valley. Occurrence of diagnostic Keokuk noncrinoid fossils in the Crawfordsville beds (e.g., *Spirifer logani*, *Productus magnus*) also confirms this age assignment.

Approximately 85 noncrinoid species from Crawfordsville have been reported (KINDLE, 54; COLLETT, 31; BEACHLER, 16; CUMINGS, 33), and these represent every major phylum, except Protozoa, known to be represented in Mississippian rocks. In abundance of species the brachiopods are most varied, consisting of 27 species, of which more than half are productoideans and spiriferaceans. Mollusks, which are next in importance, are represented by scaphopods (1 species), gastropods (9 species), pelecypods (9 species), and cephalopods (9 species). The sponges, described mainly by HALL, include 11 forms, primarily large, thin-walled, delicate dictyosponges. Coelenterates and bryozoans are each represented by six described species, though abundant fragments of the latter indicate that individuals were extremely common. The

echinoderm fauna, other than crinoids, consists of four echinoid species, two asteroids, one edrioasteroid, one ophiuroid, and three blastoids. In addition, several trilobite and plant species have been described from the area. All invertebrates, except symbiotic gastropods (*Platyceras*) and ophiuroids (*Onychaster flexilis*) lived on the bottom, and judging from the number of different forms present, a rich and varied bottom community was present in the Crawfordsville area during Keokuk time.

PALEOECOLOGY

Any attempt to explain the occurrence of the Crawfordsville crinoids is hampered by the fact that little is known about the vertical and horizontal distributions of the fauna, as well as true associations of the crinoids with other organisms. Little useful evidence can be obtained from the study of individual specimens, which now represent the vast majority of specimens collected. Thus, study of prepared slabs must be relied on for information concerning occurrence, although these represent a very limited areal distribution as compared with the whole crinoid-bearing beds. Therefore, much of the evidence needed to explain occurrences reliably cannot be readily obtained from information now available.

Previously, both hypotheses that the Crawfordsville crinoids are allochthonous and autochthonous have been proposed. COLLETT (31, p. 389) stated that the crinoids were rooted in the calcareous muds (now limestone) which directly underlie the crinoid bearing beds. The crowns were subsequently swept away by currents and deposited in a different region. SPRINGER (135) thought that the crinoids lived near the present Crawfordsville region, and therefore the locality where they were found also represents their living place. This hypothesis for the crinoid occurrence has received the widest acceptance thus far.

More recent and somewhat more detailed explanations for the occurrence have been proposed. EHRENBURG (35) considered the Crawfordsville crinoids to be allochthonous, whereas LANE (66) supported the hypothesis of an autochthonous origin for the crinoids, which lived in a shallow-water community with a muddy but well-aerated bottom. He recognized three stratified epifaunal zones, consisting of a bottom group of nonpelmatozoans, a middle zone of short-stemmed crinoids (all inadunates and camerates except *Barycrinus*, *Gilbertsocrinus*, and possibly *Dizygocrinus indianaensis*), and an upper zone of long-stemmed

forms represented by all flexibles and above-mentioned inadunates and camerates. Although we recognize that this latter hypothesis is the most realistic one, based on present knowledge of the Crawfordsville crinoids, slight revision of certain species characteristic of the different crinoid zones is desirable. We doubt if small species of *Barycrinus* (e.g., *B. asteriscus*, *B. neglectus*) had long stems. In addition, the inadunate *Pellecrinus* should probably be included with the long-stemmed forms.

The presence of various organisms living commensally with crinoids is well documented, but abundant occurrence of these forms at Crawfordsville merits some additional discussion and observations. Some crinoid species (e.g., *Platycrinites hemisphericus*, *Gilbertsocrinus tuberosus*) have mollusks preserved on nearly half of the specimens available for study, whereas such associations have been observed only rarely on others (e.g., *Agaricocrinus splendens*). Since some of these crinoids are among the most common ones found at Crawfordsville, the relationship of mollusks and crinoids probably represents one of the most abundant associations of these forms known from a single locality.

AUSTIN & AUSTIN (7, p. 73) seem to be the earliest authors who mentioned the occurrence of mollusks preserved on crinoids. In their opinion, the crinoids were carnivorous and some of them became buried while in the act of feeding on the gastropods. Similar views were held by YANDELL & SHUMARD (182), YANDELL (181), and OWEN (117). However, BILLINGS (19) suggested that the gastropods were carnivorous and fed on crinoids. MEEK & WORTHEN (76, p. 386) were the first to state that the mollusks were sedentary organisms that lived throughout most of their life attached to tegmens of crinoids, feeding on fecal matter ejected by their hosts. Numerous other authors have described this relationship, and most recently BOWSHER (22) has discussed the habits, origin, and classification of platyceratid gastropods, which characteristically have a coprophagous habit.

The conclusion that crinoids and mollusks actually lived in commensal association and that their association was not accidental is shown by (1) numerous, well-documented occurrences of gastropods with their aperture attached to the tegmen of crinoids directly over their anal opening; (2) re-entrants and sinuosities of the attached gastropod shells corresponding to irregularities on the crinoid tegmens; and (3) growth lines commonly observed on crinoid tegmens, indi-

cating that attachment was for prolonged periods, and thus that feeding of some sort by the gastropods was necessary.

Platyceratids, represented by several genera, are known to be attached to various Paleozoic crinoid species. At Crawfordsville this group of gastropods is represented by *Platyceras*, which ranges from Late Ordovician or Early Silurian through Permian time. These mollusks were not only provided with nourishment by their hosts but also a place for attachment and protection in forms in which the tegmen is surrounded by arms.

The close association of *Platyceras* and crinoids with nearly flat tegmens and commonly wide spaces between the arms suggests that choice of hosts primarily depended on suitability of places for attachment. Different gastropod species apparently did not selectively choose certain species of crinoids as hosts. This is supported by the fossil record in which the same *Platyceras* species are found attached to different crinoid species and genera. Seemingly, size of a suitable region for attachment was important, and this probably explains why *Platyceras* almost never is found attached to inadunates, which as a group are represented by rather small individuals.

Some specimens of *Platyceras* have been reported attached to crinoids with long anal tubes. WACHSMUTH & SPRINGER (159, p. 566) reported numerous examples of them attached to the base of the anal tube of specimens of *Actinocrinites multiramosus* from Indian Creek. This is the first and only known occurrence of a coprophagous gastropod attached to crinoids with long anal tubes. It suggests that the

mollusk could burrow into the crinoid without harming it (very likely), did not feed on fecal matter, or that the anal tube was not entirely efficient in keeping waste matter from falling down onto the tegmen.

On specimens available for study, *Platyceras* has been observed attached to individuals of *Platycrinites hemisphericus*, *Gilbertocrinus tuberosus*, *Agaricocrinus splendens*, *Cyathocrinites multibrachiatus*, and *Springericrinus magniventrus*. In addition, BOWSER reported a similar association on specimens of *Cydracrinus*, an inadunate.

More rarely, the ophiuroid *Onychaster flexilis* is preserved in close association with crinoids, but unlike *Platyceras* it is not known whether the host provided nourishment or if it merely served as a suitable place for attachment, presumably temporary, because locations of the ophiuroids vary in different fossils. WACHSMUTH & SPRINGER (159, p. 566) described such an occurrence on specimens of *Actinocrinites multiramosus* from Indian Creek, and stated that the arms of the ophiuroid encircle the tegmen of the crinoid with the ophiuroid's mouth directed downward. CLARK (1908) illustrated a similar association from Crawfordsville of *Onychaster* entangled in the arms of an inadunate, *Barycrinus hoveyi*.

The profuse occurrence of commensal organisms preserved on Crawfordsville crinoids is primarily the result of (1) presence of numerous specimens of crinoids suitable for attachment; (2) exceptional preservation of the fauna; and (3) muddy bottom conditions, which at least in part probably caused such forms as *Onychaster* to seek a more desirable habitat than found on the sea floor.

CRAWFORDSVILLE CRINOIDS

By JAN. F. VAN SANT

INTRODUCTION

The discussion of the Crawfordsville crinoid fauna is divided into two parts, (1) morphological features, and (2) a critical but not exhaustive treatment of the crinoid species. Opportunity to disarticulate numerous specimens has resulted in a more or less independent study of the articulations of crinoids. Because Crawfordsville specimens were used extensively in this study it is appropriate that the results appear here. A general review of structural features found on both

Paleozoic and post-Paleozoic crinoid ossicles is also included below.

MORPHOLOGICAL FEATURES

ARTICULATION OF CRINOID OSSICLES

GENERAL DISCUSSION

Permission to disarticulate selected Crawfordsville specimens belonging to the Walker Museum (University of Chicago) has resulted in obtaining

new information about union between plates of Mississippian crinoids. For this unusual opportunity to study basic problems relating to crinoid morphology I am indebted to J. MARVIN WELLER for permitting this phase of the study to be conducted and to R. C. MOORE for interest shown and valuable advice given during the course of preparing specimens and interpreting observed structures.

The mode of union of various plates belonging to post-Paleozoic crinoids has received considerable attention and the nature of articulations of these skeletal elements is among the most important features used in crinoid classification. Unfortunately, comparatively little precise information is available concerning the character of plate articulations in Paleozoic forms. This is primarily because (1) few paleontologists have been willing to destroy well-preserved crinoids in order to study the mode of union of their plates; (2) the plates of most fossil crinoids are so firmly joined together that efforts to separate them mechanically commonly result in fractures across the plates rather than breaking apart along sutures between them; (3) little attention has been given to isolated crinoid fragments that commonly show well-preserved articular surfaces; and (4) during the period in which most crinoids were collected major emphasis has been given to naming new species and genera instead of detailed study of their morphology.

Knowledge that some crinoids have distinct structures on surfaces between plates is not new, and in fact several early workers stressed types of articulations (or absence of them) in their definition of major crinoid groups. These paleontologists did little more than recognize the general appearance of the unions, and commonly their division of major groups lacked accurate definition. J. S. MILLER (84), who first attempted to erect a classification of all known crinoids, proposed four divisions based largely on the nature of articular surfaces of skeletal parts. He grouped forms with "well-developed" articulations in the Articulata and those with "imperfect" unions in the Semi-articulata. Crinoids with plates united by "sutures and lined by muscle integument" were placed in the Inarticulata, and the division Coadunata was proposed for crinoids with fused plates. Later, JOHANNES MÜLLER (1841) assigned almost all Paleozoic crinoids to a single group (Tesselata), which lacked well-developed articulations such as characterize most post-Paleozoic crinoids. WACHSMUTH & SPRINGER (157) divided their order Palaeocrinoidea into three groups: Camerata, Inadunata, and Artic-

lata (=Flexibilia as now recognized). These groups were distinguished in part by mode of union of the plates and in part by structure of the arms. The camerates were characterized as having thecal plates "solidly united by suture" and the so-called articulates included forms in which "the test is pliable." Other authors (e.g., BATHER, 12; MOORE & LAUDON, 109) have also considered types of articulations important in defining major groups of crinoids (above genus and species levels).

Special emphasis on the study of articulations in Paleozoic crinoids has been given by a few paleontologists who have studied Pennsylvanian and Permian forms (e.g., MOORE, STRIMPLE, WANNER), such studies being mostly concerned with various characters observed on the radial facets of inadunates. However, UBAGHS (148) has added considerable knowledge to understanding the mode of union of thecal and brachial plates of camerate crinoids and SPRINGER (136) has described and illustrated articulations observed in the Flexibilia. Others (e.g., BATHER, 11, 13; MOORE, 105; UBAGHS, 150) have described articulations more generally.

Because many structures and types of unions occurring on Paleozoic forms resemble those found on post-Paleozoic crinoids, a summary of present knowledge concerning articulations found on living forms is included here. Classification and definition of major terms commonly applicable to mode of union between plates in both living and fossil crinoids are also included. This rather brief discussion will be followed by information obtained from study of articulations observed in selected Crawfordsville specimens and Paleozoic forms in general.

Satisfactory methods for disarticulating Crawfordsville specimens were never entirely achieved because most of them were too firmly cemented together to allow mechanical separation of the plates. Several weathered specimens were disarticulated with the aid of dental instruments and a drill, but the majority were treated with caustic potash pellets (KOH) in efforts to break down the matrix. The potash takes up water from the air, and the concentrated solution of alkali thus formed attacks clay particles. This method is not entirely satisfactory because the resulting solution attacks the calcareous plates as well as the matrix, and even with careful application details of articular facets are easily destroyed. Prolonged soaking in water loosened the matrix enough to be easily worked, but little loosening of the plates resulted. Specimens in which the matrix has a high

clay content (75 to 100 per cent) are easily disarticulated by placing the specimen just above water level and boiling in a pressure cooker. Unfortunately, this procedure could not be used with Crawfordsville specimens since clay content is only 30 to 40 per cent. Good results using dilute hydrofluoric acid (40 per cent) were obtained; however, unless carefully applied, the acid will completely destroy the fine articular structures. This method was particularly useful to clean matrix from surfaces that had been mechanically disarticulated.

OBSERVATIONS BASED ON POST-PALEOZOIC FORMS

Histological study of Recent crinoids has shown that they lack regular muscle layers in a body wall that is stiff and more or less immobile because of the presence of endoskeletal ossicles. As a result, the plates of crinoids are united only by elastic tissues that have been called ligaments; however, their true nature is still a matter of dispute. Judging from their various functions, many of these are not true ligaments in the usual anatomical sense, that is, bands of connective tissue serving merely to hold structures and organs in place and not possessing controllable contractile power. Typical muscle fibers are found only in arms and pinnules of Recent crinoids and are inferred to have been present between radials and arm ossicles (brachials) in certain fossil forms.

BOSSHARD (20) studied the histological difference between muscles and ligaments in Recent crinoids (*Antedon*), and concluded that they have different structures and capacity for coloring. According to his conclusions, muscles must be active flexors and in the case of crinoids with muscular articulations, they flex the arms ventrally (inward). Ligaments, on the other hand, have no active flexing power, but serve merely as elastic antagonists, which automatically bend the arms dorsally (outward) upon relaxation of the muscles. As pointed out by GISLÉN (37), this definition of differences is not entirely acceptable because some parts of crinoids (e.g., cirri, some ossicles connected by synarthries, etc.) have only ligaments, but they seem also to have active contractile power. Thus, ligaments of crinoids do not have only a passive function, as for example ligaments in pelecypods, but take part in active flexions of the arms, pelma, and even thecal plates in some forms. Unfortunately no recent histological studies have been made on crinoid tissue, and thus it is highly probable that early studies failed to distinguish properly between ligament and

muscle tissues. With modern equipment and techniques a study of this sort without doubt would add significant information concerning the mode of union between crinoid ossicles.

As suggested by GISLÉN (37, p. 63), ligamentary and muscular tissues of crinoids seem to be rather closely related physiologically, but because their histology is seemingly distinct, the two terms are retained in this paper in order to have clear and familiar distinction. It is conceivable that muscles and ligaments could be combined into a single bundle, but without modern techniques the muscle fibers probably could not be detected.

One of the first systematic treatments of the mode of union between crinoid plates was by CARPENTER (24) in his monograph on crinoids obtained by the Challenger Expedition. He recognized three types of articulation between arm plates (brachials); these were designated as (1) *muscular*, (2) *bifascial*, and (3) *trifascial articulations*. Other connections were by *suture* and these were referred to as *syzygy*, *synostosis*, and *ankylosis*. MINKERT (102) and REICHENSBERGER (121) recognized only two major connections between brachials. They used the term *synarthrie* (synarthry) for movable articulations, and *syzygie* (syzygy) for relatively immovable ones. Both of these, as now used, refer to particular types of ligamentary articulations. Work by BATHER (13) and especially A. H. CLARK (26, 29) on Recent crinoids contributed much to understanding of crinoid articulations and development of useful terminology for them. The most comprehensive classification, which attempted to relate articulations found in both fossil and living forms was by GISLÉN (37, p. 65). His classification with slight modifications is used in the present study, and according to MOORE (personal communication) will be adopted in the crinoid volume of the *Treatise on Invertebrate Paleontology*. The various classifications that have been proposed to describe modes of union between crinoid plates are shown on Table 2. Equivalent terms are not necessarily arranged horizontally except those used by GISLÉN and adopted for the *Treatise*. Fig. 9 illustrates common types of articulations found in Recent crinoids and morphological terms applied to various structures.

The connections between plates that are joined by a combination of ligament and muscle fibers are termed *muscular articulations*. These unions are well developed between certain brachial ossicles in Recent crinoids, but are also present in many Mesozoic and

TABLE 2. Terminology Employed for Types of Articulations

Equivalent terms are not necessarily arranged horizontally except in last two columns.

	MICKERT, 1905	A. H. CLARK, 1915	SPRINGER, 1920	REICHENSPEGER, 1912 GISEN, 1924	MOORE, et al. <i>Treatise</i>
I. Muscular articulation	Toward flexibility	I. Muscular articulation	I. Articulation	I. Muscular articulation	I. Muscular articulation
II. Bifascial and trifascial articulation	I. Loose suture II. Imperforate articulation III. Perforate articulation	A. Straight articulation B. Oblique articulation	A. Concave-convex surfaces B. Imperfect articulation	A. Muscular articulation (ss) B. Pinnular articulation	A. Symmetrical articulation (straight) B. Asymmetrical articulation (oblique)
III. Sutures	Toward rigidity	II. Nonmuscular articulation	C. Complete articulation	II. Ligamentary articulation	II. Ligamentary articulation
A. Syzygy	I. Close suture	A. Synarthry	II. Suture	A. Immovable articulation	A. Immovable articulation
B. Synostosis	II. Syzygy	B. Cryptosynarthry	A. Close suture	1. Close synostosis	1. Zygosynostosis
C. Ankylosis	III. Ankylosis	C. Syzygy	Syzygy	2. Syzygy	2. Syzygy
		D. Pseudosyzygy	Ankylosis	3. Pseudosyzygy	3. Cryptosyzygy
		III. Suture	B. Loose suture	4. Ankylosis	4. Ankylosis
		A. Close suture			5. Symmorphy
		B. Loose suture			B. Movable articulation
		IV. Stem unions			1. Synostosis
		A. Synarthry			2. Synarthry
		B. Stem syzygy			3. Cryptosynarthry
		C. Sutures			4. Trifascial articulation
					5. Cryptosymplexy
					III. Stem articulation
					1. Zygosynostosis
					2. Synostosis
					3. Synarthry
					4. Symplexy
					5. Cryptosymplexy

[* Includes patelloid sculpture and loose synostosis.]

Paleozoic forms. In the latter they are most common between radials and primibrachs and between various brachials; however, some rather specialized forms may have them between thecal plates (e.g., between basals and radials of some Calceocrinidae). In post-Paleozoic forms, muscular articulations are characterized by the presence of a more or less straight ridge (*transverse ridge*) normal to the longitudinal axis of the plates. This ridge acts as a fulcrum on which movement occurs (Fig. 9). It may divide the plate symmetrically (*straight muscular articulations*) or asymmetrically (*oblique muscular articulations*). The surface bears five depressions (*fossae*) that house ligament and muscle fibers. A single, large hemispherical fossa located dorsal to (outside of) the transverse ridge is termed the *dorsal ligamentary fossa*. It serves to lodge the *extensor ligament*, which pulls the arms out, away from the theca. On the ventral (inner) side of the transverse ridge are two *interarticular ligament fossae*. Their function has never been clearly stated, but judging from their position and relative sizes these ligaments seem to serve primarily as antagonists to the paired flexor muscles, which are lodged in the ventral-most pair of depressions (*ventral muscular fossae*). In addition, ligament pits and openings for passage of nerves can normally be seen on many articular surfaces.

Evidence found in some Paleozoic crinoids indicates that both muscular and ligamentary fibers occurred between certain plates. Some structures that are common to both fossil and living crinoids suggest similar modes of union between plates. Conventionally, any articular facet that possesses a ridge has been considered to be a muscular articulation, as opposed to facets having relatively plane surfaces without specialized structures, these latter being classed as ligamentary (nonmuscular) articulations. Well-developed interarticular ligament fossae are commonly lacking in many forms, and thus if muscles developed in the ventral portion of the facet they were not powerful enough to require antagonists, as in post-Paleozoic forms, or the tissues were composed entirely of ligamentary fibers. In Pennsylvanian and Permian inadunates with muscular articulations only three relatively large concave depressions commonly are observed, two located inward from the transverse ridge and the other on the outer side of this ridge. The inner fossae supposedly lodged muscles (and ligamentary tissue) that by analogy with those in Recent crinoids caused the arms to be flexed inward.

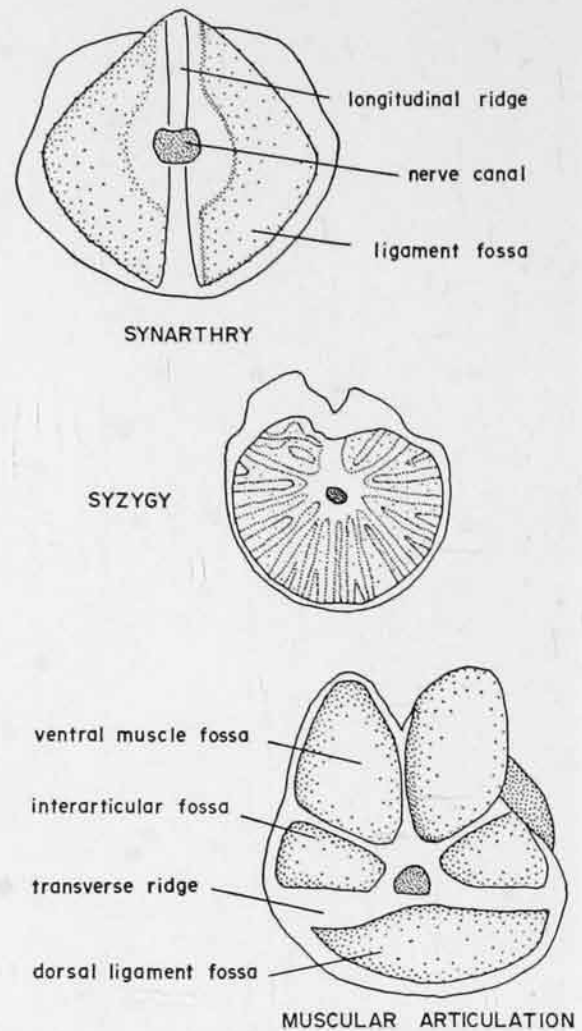


FIGURE 9. Structure and types of articular surfaces between brachials of some post-Paleozoic crinoids (37).

One of the perplexing problems in trying to interpret these structures is to explain why most crinoids having arms attached to the dorsal cup are preserved with the arms directed upwards. If the ventral fossae actually lodged muscle fibers, relaxation of the fibers would occur upon death, and thus the elastic antagonists (dorsal ligaments) would tend to pull the arms outward, away from the theca. This would be similar to what commonly occurs in pelecypods after death. In these mollusks the two valves are pulled apart by contraction of ligamental fibers. The answer to this question is that most fossil crinoids in which arms are preserved probably do not have well-developed muscular articulations, but the brachials are nearly im-

movable. Arms preserved in place are somewhat rare in most Pennsylvanian and Permian inadunates, and because most of them presumably had muscles, the reason for loss of the arms in fossilization can be easily explained. Upon death the muscles relaxed and the dorsal ligament tended to pull the arms away from the theca. Further, it is probable that dead muscle fibers do not have the binding power that ligaments do.

Articulations in which only ligaments are present are termed *ligamentary articulations* (nonmuscular). They may be either movable or immovable (relatively). Ligamentary articulations are more common than muscular articulations in both living and fossil crinoids, and in most Paleozoic forms they were the only mode of union between ossicles. Because of their abundance and variety, a rather complex set of terms has been adopted.

Synostosis is a movable articulation of plates characterized by an even, smooth, or slightly rugose nature of opposed articular surfaces, which tend to be somewhat biconcave. Articulation of this sort is common in the distal portion of the arms in many Recent forms and between brachial joints in many fossil forms. Synostosial articulations are flexible in all directions, but they allow only very slight movement.

A *synarthry* is a slightly movable articulation that is flexible in two directions normal to a central articular ridge that separates two rather large hemispherical ligament areas (Fig. 9). This type of articulation corresponds to CARPENTER's bifascial union. It occurs between brachials in many fossil and living forms, as well as between cirrals and stem ossicles of some crinoids (e.g., Platycrinidae, Bathycrinidae). In addition, many camerate genera seem to have this type of articulation developed between the fixed-brachials and brachials; however, as discussed below, these are entirely different structures which are termed *pseudosynarthries*. A synarthry in which the fossae are weak and indistinct is termed a *cryptosynarthry*. These are only slightly movable, and according to GISLÉN form a transition from synarthry to a synostosial type of articulation. A modified synarthrial type of articulation termed an *embayed synarthry* is characterized by a broadly rounded projection of the distal ossicle into a complementary hollow of the proximal ossicle. An *even synarthry* is characterized by general evenness of opposed faces of adjoined brachials united by a synarthry.

A surface characterized by three concave ligament areas is known as a *trifascial articulation*. It allows

maximal movement in two directions (commonly dorsoventrally), and occurs commonly between radial and brachial plates in many Paleozoic genera. Seemingly it was antecedent to true muscular articulations such as crinoids developed in Devonian and Mississippian time. Many Pennsylvanian and Permian crinoids also exhibit it, especially between distal brachials. In addition, certain arm joints in flexible crinoids also have this type of articulation. Next to true muscular articulations trifascial unions provide the most flexible type of union known. It is quite probable that some muscle fibers were present in these articulations, thus providing controllable contractile power. This type of union is rather rare in Recent crinoids, but it has been reported in several genera (e.g., *Pontiometra*, *Stephanometra*).

Many crinoid ossicles are united in such a manner that only very slight differential movement or none at all occurs. These plates have immovable articulations. Those possessing flat, smooth joint-faces for attachment of very short ligamentary fibers are called *zygosynostosial articulations*. They commonly have moderate amounts of calcareous deposits on their faces. Mostly they are immovable, but in some crinoids extremely slight movement is possible in all directions. In post-Paleozoic forms it is a common mode of union between thecal and stem ossicles, and in many Paleozoic crinoids it is the most common union between brachials, as well as between cup plates. Complete fusion of plates (*ankylosis*) is rare in living crinoids, but rather common in fossil forms.

One of the most common and often incorrectly designated types of immovable articulations is named *syzygy*. As originally proposed (MÜLLER, 113) it referred to sutural connection between arm-joints (brachials) and was used to differentiate it from muscular articulations. Usage has come to give several other meanings to the term (e.g., interval between two syzygies, joints connected by syzygies, etc.), and not until BATHER (1896) reviewed the whole subject was the term properly explained. As now understood, a syzygy is a particular type of nearly immovable ligamentary articulation characterized by the presence of fine, radiating ridges and intervening depressions that begin near the center of an ossicle and extend to near its periphery. The ridges, incorrectly called crenellae by BATHER (13) and other authors, are here designated as *culmina* (sing., *culmen*), in agreement with terminology adopted for use in the *Treatise on Invertebrate Paleontology* (R. C. MOORE, personal communication), because this name signifies

ridge; the furrows are rightly defined as *crenellae*, since this name is the Latin designation for small grooves or troughs. It seems unwise to perpetuate usage that defines ridges as grooves (*crenellae*). Ridges and furrows of apposed ossicles respectively coincide with one another, ridge against ridge and furrow opposite furrow. The furrows (true *crenellae*) contain short connective-tissue fibers that may be completely or only partly developed. The extent to which individual syzygial faces display the defined characters in part depends on the age of an individual. Syzygies occur in most of the immovable arm articulations of comatulids and in some fossil forms of other groups. Articulations of syzygial type, but with rudimentary and indistinct structures are called *cryptosyzygies*.

Similar radiating ridges and furrows are common on stem ossicles of Paleozoic forms, but instead of having apposed ridges (*culmina*) meeting one another, as in true syzygies, they interlock with furrows (*crenellae*) on adjoining columnals. These commonly have been called syzygies, but because they are entirely different structures, they are now referred to as *symplexies*.

As will be seen below, some articulating surfaces cannot be classified easily in any of the above-mentioned types. Until more information is available, it is judged best only to describe these unions and not to propose formal terms for them.

OBSERVATIONS BASED ON PALEOZOIC FORMS

Many types of unions between plates of Paleozoic crinoids so closely resemble those found in Recent forms that it is rather simple to interpret their degree of flexibility and the mechanism of the articulations. Others appear to be modifications of known types (commonly more primitive), and as mentioned above, some are completely unknown in existing crinoids. The amount of flexibility between plates is largely governed by the relationship between size of fossae and amount of surface area of a facet in contact with adjacent articular surfaces. Thus, a facet with a relatively large fossa surrounded by only a narrow rim is judged to be more flexible than one in which the depression is smaller, or one in which a large fossa surrounds numerous small elevated ridges that are in contact with similar structures on the apposed surface. In addition, the depth of a ligament depression may reflect amount of flexibility in some degree. Distinction between muscular and ligamentary articu-

lations is commonly difficult to determine in Paleozoic crinoids, especially in pre-Pennsylvanian forms. In the present study, facets considered indicative of a muscular articulation must have a distinct transverse ridge that invariably separates a single distinct dorsal depression from a pair of ventral ones, as well as associated ligamentary pits and fossae. Trifascial ligamentary articulations are most easily confused with muscular unions, especially in forms with poorly developed transverse ridges. However, they lack inter-articular ligamentary fossae, pits, and other characters of the facets.

Defining muscular articulations in this manner, nearly one third of known inadunate genera possess this mode of union between radials and first primibrachs and commonly between other brachials. They represent approximately 125 genera that are assigned to 18 families. This is rather significant when one remembers that, as now classified, the inadunates became nearly extinct during Permian time and vanished in the Triassic. Because the Articulata were undoubtedly derived from Paleozoic forms (although which ones is yet doubtful), it is probable that changes are needed in classification of crinoids in order to provide a more natural classification. Based on present knowledge, muscular articulations first appeared in Devonian forms (glossocrinids and scytalocrinids) and became well developed and common in Carboniferous and Permian crinoids (e.g., blothrocrinids, pachylocrinids, pirasocrinids, etc.). Similar articulations are seen in *Encrinus*, which occurs in Triassic rocks.

Muscular unions have also been reported in the Flexibilia, but no post-Paleozoic forms are known to have been derived from this group of crinoids. The articulation between brachials in several genera (e.g., *Forbesiocrinus*, *Taxocrinus*, and probably many more) has a well-developed transverse ridge; however, as discussed below, the fossae are unlike those in inadunates and post-Paleozoic forms, and the ridge does not seem homologous to those on inadunates and post-Paleozoic forms. I am not aware of any camerate crinoid that has true muscular articulations although well-developed articulations consisting of fossae and ridges have been observed on the surface between pinnules and brachials and between uniserial brachials.

Development of articulations in various crinoids indicates that articular surfaces can form between almost any plates in the crown. Thus, it seems that in almost any region articulations can appear if the

mechanism would be advantageous to the organisms. A prime example of this is found in the highly specialized reef-dwelling inadunates belonging to the calceocrinids in which a well-developed articulation is present between certain basal and radial plates. Unexpected articular surfaces also occur between certain tegmental spines and apposing ossicles of the tegmen in some upper Paleozoic inadunates.

FLEXIBILIA

As the name implies, crinoids referred to this subclass are characterized by flexible modes of union between plates. Thecal plates are commonly connected by surfaces in which rather large and deep depressions are surrounded by a narrow rim that possesses alternating ridges and furrows (crenulations). These articulations have been called loose sutures (=synostoses), but they differ from typical ones in depth of fossae and rimmed peripheral edges. However, they probably were derived from a typical synostosomal type of articulation. As discussed below, the degree of mobility between thecal plates undoubtedly varied greatly in different species of flexible crinoids. In most forms brachials were united by a modified muscular or ligamentary articulation, which lacked a distinct transverse ridge. Some surfaces appear to be similar to trifascial ligamentary articulations. Unlike Paleozoic crinoids with well-developed muscular articulations, the distal facet of the radials in Flexibilia commonly lacked true muscular connections. In many forms the transverse ridge is indistinct or absent and the ventral depression is single, rather than paired, thus causing the distal surface of the radial plates to appear more similar to other thecal plates than to arm ossicles. Brachials in many forms, especially Taxocrinidae, Ichthyocrinidae and later Sagenocrinitidae, are characterized by arcuate curvature of their transverse sutures. These so-called "patelloid structures" are discussed in more detail later. Their main function was to limit the outward flexibility of the arms.

Surprisingly little information is available on details of union between the plates of flexible crinoids; however, most workers agree that flexibility is one of the most characteristic features of this group of crinoids. Some genera (e.g., *Nipterocrinus*, *Amphicrinus*) had rigid thecas, but these seem to be exceptions. SPRINGER'S (136) classic monograph on the Flexibilia contains many excellent illustrations of articular surfaces (e.g., pl. 24; pl. 25, fig. 5, 6; pl. 39, fig.

17, 18; pl. 57, fig. 6, 7; pl. 61, fig. 4-9), but few descriptions of them were included.

Detailed information on articulations is available for only a single species of *Forbesiocrinus* (a sagenocrinitid), and in these, knowledge of articular surfaces based on a single individual is lacking. Thus, exact relationships of adjacent surfaces are unknown. SPRINGER purchased numerous disarticulated plates of *F. nobilis* from Lower Carboniferous rocks at Tournai, Belgium, for the explicit purpose of studying the mode of union between plates of these crinoids. The rock containing most of the ossicles consists of a very soft shale so that the fossils commonly become disarticulated when they are freed from the matrix. For purposes of comparison, the articular surfaces of *F. nobilis* will be considered as "typical" articulations of flexible crinoids, realizing, of course, that when more information is available a more appropriate scheme of classifying and comparing them may be adopted.

Six primary types of articulations existing between ossicles of *Forbesiocrinus nobilis* are explained and illustrated in the following discussion as basis for comparison with articulations observed in the Crawfordsville species, *Taxocrinus colletti* and *Onychocrinus exculptus*.

ARTICULATIONS IN FORBESIOCRINUS NOBILIS

Type 1. Most flexible crinoids in which the stem has become detached from the crown show the infrabasals adhering to the proximal stem ossicle, rather than to succeeding thecal plates. This clearly indicates that the proximal surfaces of the infrabasals and topmost columnal are more firmly united than plates of the crown. Although the true nature of this union is not known, external appearance suggests close resemblance to the articulations between stem ossicles (symplexies or zygostynostoses) or the union of crown with stem may be ankylosed. The same type of union also appears to occur between adjoining infrabasal plates.

Type 2. (Fig. 10,1,4a,5). All thecal plates, except proximal and lateral surfaces of infrabasals and distal faces of radials, are united by a similar type of articulation. The same type of union also occurs on the lateral surfaces of the proximal primibrachs up to approximately the middle of the second primibrachs (Fig. 10,7a). These surfaces are characterized by a single, rather steep-sided depression. Around the outer margins is a well-developed peripheral ridge that is covered by nearly straight and rather coarse crenulations, which interlock with similar structures on the adjacent surface. The outer (dorsal) portion of the rim is normally 2 to 3 times as wide as

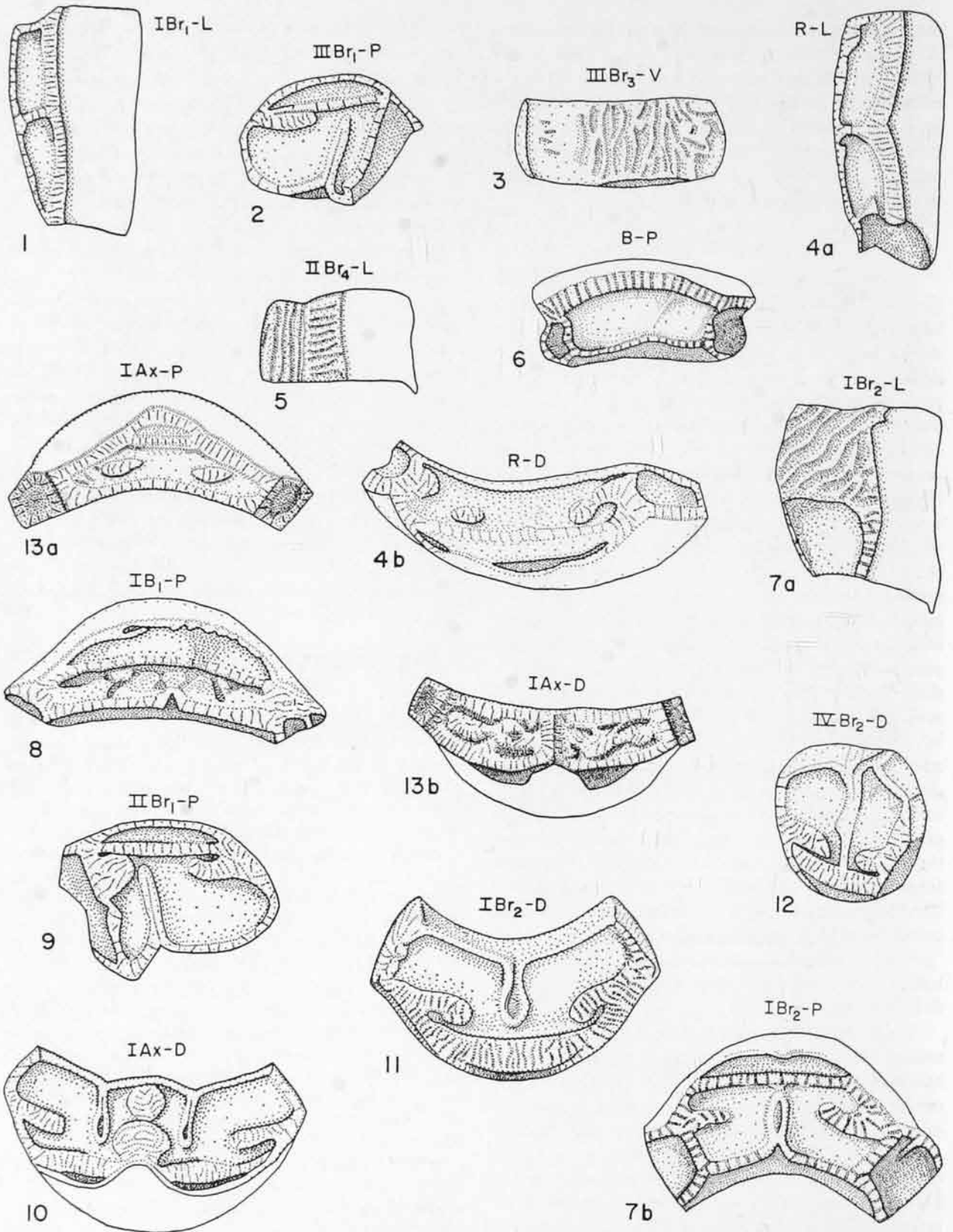


FIGURE 10. (See facing page.)

other peripheral margins (Fig. 10,4a,5). In other species of *Forbesiocrinus* the proportion of size of fossa to rim varies, thus permitting greater or more limited mobility of plates. Commonly, as developed in *F. agassizi*, numerous irregular raised areas occur within the fossa causing restricted movement between ossicles (Fig. 10,13a,b).

According to definition, this type of articulation must be considered a ligamentous union. Similar general patterns occur in other crinoids (e.g., between radials and first primibrachs in *Platycrinites*), but much less mobility occurred in these forms. The union between thecal plates in *Forbesiocrinus* most closely resembles synostoses, but here they are much more specialized and afforded much greater movement between plates than true synostosal articulations. In the few flexible genera that had rigid thecas the mode of union between plates was probably by more typical synostoses.

Type 3. (Fig. 10,4b,7b,8,9). Unlike Paleozoic crinoids with muscular arm articulations, the union between radials and proximal surface of the first primibrachs in *Forbesiocrinus* somewhat resembles articulations between other plates of the theca. Most commonly the surface consists of a single large dorsal and ventral fossa, which are separated by a narrow, commonly indistinct transverse ridge. The lateral margins of the surface have relatively large flat crenulated areas similar to the peripheral rims on type 2 articulations. Within the ventral fossa are two elevated areas that may or may not be connected with the crenulated marginal areas.

Unions with this type of articulation may be imperfect muscular articulations; however, more likely they represent a specialized type of ligamentary union, as no supplementary ligamentary fossae or pits are observed on any surfaces. Further, it differs from muscular unions in having a very indistinct narrow transverse ridge, and instead of paired ventral fossae, it has only a single large one. The crenulated lateral margins and elevated areas in the ventral fossa suggest that mobility between the apposed surfaces was somewhat restricted. This possibly could have been due to need for greater rigidity in the proximal portions of the arms.

Type 4. (Fig. 11). The brachials of known forms of *Forbesiocrinus*, as well as most Crawfordsville species of *Taxocrinus* and *Onychocrinus* discussed below, are characterized by well-developed arcuate transverse sutures. In these forms the proximal margins of the dorsal portion of the brachials bend downward, commonly very abruptly, and they overlap similarly shaped shallow sockets on the outer distal portion of the plates below. The

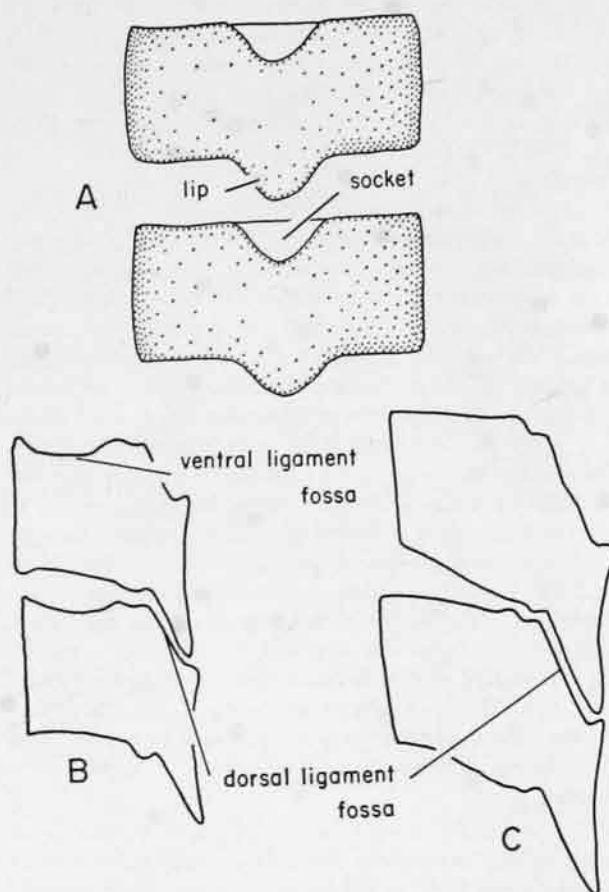


FIGURE 11. Diagrammatic representation of the so-called "patelloid structures" developed on some flexible crinoids (partly after Springer, 1920).—A. Dorsal (outer) side of two adjoining brachials.—B. Cross section through center of adjoining brachials showing maximum length of projecting "lip" and apposing "socket."—C. Cross section along side of patelloid structure showing reduction in size of lip and socket.

marginal contact areas of both the extended process and socket have culmina and crenellae, thus restricting lateral movement of the plates when the structures were fitted together. This type of structure is unknown in other Paleozoic crinoids; however, in some Recent pentacrinids similar arcuate sutures are known (CARPENTER, 24, pl. 29, fig. 2).

Because the arcuate "lip" portion of the sutures is thin, fracture along its upper margin commonly occurs. HALL (40, p. 630), who originally described this feature,

FIGURE 10. Plates of *Forbesiocrinus* showing well-developed articular structures judged to be ligamentary in nature, allowing considerable movement between ossicles. 1-12. *F. nobilis* DE KONINCK & LE HON, from Lower Carboniferous rocks at Tournai, Belgium (after Springer, 1920). 13. *F. agassizi* HALL, from Osagian (Burlington Limestone) at Burlington, Iowa. [Explanation: Each plate is designated by its standard symbol and diagrams are arranged so that on a proximal view the dorsal (outer) side is directed upward and on a distal view it is downward; views are indicated by D (=distal), L (=lateral), P (=proximal), and V (=ventral) following the plate symbols. All figures X4.]

thought that the broken pieces were actually separate ossicles, which he called "patelloid plates." BATHER (13, p. 190) indicated that these plates were common ossicles in many flexible crinoids. The true nature of the structures was not clearly understood until SPRINGER (136, p. 43-45) described them and explained their true function.

The mechanics of the structure as explained by SPRINGER was nearly correct, but the dorsal ligament was probably not contractile as he suggested. He postulated that when the arms were folded the dorsal elastic ligament was stretched so that the proximal extensions would be slightly separated from their sockets. With extension of arms outward the fibers would be forced close to the inner portion of adjoining socket, thus allowing arms to be extended for only a limited distance. Movement was also limited by the crenulated apposed surfaces of both socket and extension, which served to restrict movements in lateral directions. SPRINGER thought that the dorsal ligament had active contractile power and that it acted to pull the process firmly into the socket; however, if the union in this portion of the connection was actually by a true ligament, it would serve merely as connective tissue holding the "lip" and "socket" together. However, the small size and smooth surface of the dorsal fossa do not suggest attachment of tissue capable of extending arms (viz., well-developed muscle fibers).

On other Paleozoic crinoid plates having both dorsal and ventral depressions the former was approximately on the same level as the latter ones, and both occurred on the upper surface of the plates. However, in flexible forms with arcuate sutures the dorsal ligament area is commonly in an oblique position, extending along the outer sloping surface on distal articulations and behind the extending "lip" in proximal ones. Fig 11, B,C illustrates relationships of this structure on adjacent plates.

Type 5. (Fig. 10,2,10-13). The mode of union between successive brachials has been described in literature as muscular articulations; however, as discussed below, these unions probably represent highly specialized ligamentary articulations that developed ridge-fossa patterns superficially resembling those on true muscular surfaces. The dorsal ligament area on the distal surface of the brachials is confined to a rather thin region on the outer (dorsal) sloping surface of the plates. As shown on Fig. 11, the proximal faces of the dorsal ligaments were attached to the inside of the patelloid extensions. The size and shape of this ligamentary area is directly proportional to the size and shape of the patelloid structure. Along the outer margin of the more or less upper-level portion of the articular facet the structure that has been called the "transverse ridge" occurs. From examination of SPRINGER's illustrations (e.g., pl.

24, fig. 8b, 10a, c, 11a, 15, 17d) this structure appears more closely related to the outer crenulated margins of the plates than to a typical transverse ridge, as shown below in Fig. 23. Considerable doubt exists in my mind that this ridge is homologous to the transverse ridge present in many inadunate crinoids. Rather, it seems to represent a modified dorsal marginal region that resulted because of the sloping outer dorsal ligament area. Ventrally, the two large fossae that lodged ligamentary or muscular fibers are found. These are separated by a narrow interarticular ridge that has a slitlike groove in which a pit or nerve opening commonly can be observed near the distal end. The longitudinal interarticular ridge ends before meeting the so-called "transverse ridge" on most surfaces. Along the lateral margins of the articular surfaces the crenulated rim extends into the fossa areas as two broad lobes, which also acted as contact surfaces between apposing surfaces. No surfaces were observed with interarticular fossae, which would serve as antagonists to the ventral muscles.

Type 6. (Fig. 10,3,7a). Along the lateral surfaces of most connecting brachials, ventral sides of brachials in contact with the peristome and between distal margins of interbrachials, the articular surfaces become folded into irregular corrugations. As typically developed, the folds are rather coarse and subparallel; also, commonly they bifurcate or become discontinuous. Along ventral sides of plates they are longitudinally aligned, but on lateral sides they are oriented normally or obliquely to the longitudinal axes of the plates. They gradually diminish in size distally and finally disappear above the tertibrachs. On the proximal primibrachs the lateral surfaces are connected by type 2 articulations; however, about at the middle of the second primibrachs the mode of union abruptly changes to corrugated surfaces, which normally continue distally to the quartibrachs. The ventral connections with peristome normally begin above the second secundibrachs. This type of articulation is judged to be very rigid, allowing little or no movement along apposed surfaces.

Comparison of articular surfaces of *Forbesiocrinus nobilis* with other species of the genus indicates that the Belgian form had a more loosely connected theca and greater mobility of arms than other known species. Union between plates of other species is known only in a few, and in these only some articular surfaces are known. Although the general types (as designated in this study) are present, in some species considerable modifications can be noted. In the Burlington species, *F. agassizi*, the union between thecal plates, distal faces of radials, and lateral margins of proximal brachials is a modified type 2 articulation that has numerous elevated areas within the fossa (Fig. 10,13a,b). Thus, considerably less mobility was possible than in *F. nobilis*. Also, articular surfaces of some primibrachs and secundibrachs

are covered largely by crenulated areas that were in contact with apposing surfaces, and thus an almost rigid connection resulted. In *F. saffordi*, a very large species and one of the geologically youngest known forms of the genus, type 2 union is completely unknown. The thecal plates are united by a series of irregular grooves and ridges and by very small modified fossae or pits. The primibrachs have well-developed rim areas and much-reduced fossae, thus causing the proximal portions of the arms to be only slightly movable.

ARTICULATIONS IN TAXOCRINUS COLLETTI

Comparison of illustrations shown on Figures 10, 12, and 13, and information given on Table 3 indicate that considerable differences exist in details of articular surfaces between individual ossicles of *Forbesiocrinus no-*

bilis and *Taxocrinus colletti*. However, general types of articular surfaces are similar in both species and those recognized above for *Forbesiocrinus* commonly can be identified easily on corresponding plates of *Taxocrinus*.

Besides major differences in anal structure, development of interbrachials, and mode of attachment of peristome (considered in detail below), certain plates show considerable differences in the size and shape of ossicles. In both *Forbesiocrinus* and *Taxocrinus* a gradual increase in these features of the ossicles from radials to primaxils can be distinguished. Distally, the secundibrachs remain about the same in size and shape (commonly to the tertibrachs); beyond this, the plates gradually become thinner and relatively few differences can be observed between genera. Below secundibrachs, ossicles of *F. nobilis* are proportionally only about half to

TABLE 3. *Articulations between Ossicles of Taxocrinus colletti*

TYPE	LOCATION	DESCRIPTION	COMPARISON with <i>Forbesiocrinus nobilis</i>
1	Between IBB and stem and probably between IBB.	Culmina and crenellae extending completely across surface, with no confined single fossa; ligaments between crenellae.	Probably similar.
2	Between thecal plates lateral sides of iBrr, and lateral sides of proximal IBrr.	Crenulations long, well-developed, and rather coarse. Subcentral shallow fossa narrow, but wide; extending to near margin of plate. Thus, lateral crenulations not normally developed, except on iBrr.	Differs in having larger crenulated areas and less area for fossa, which is considerably shallower, and shorter but relatively wide. Theca judged to be more rigid than in <i>F. nobilis</i> .
3	Between RR and IBrr.	Normally consisting of rather large dorsal ligament; single large, but shallow ventral fossa; "transverse ridge" distinct, rather long and extending completely across surface of plate. One aberrant specimen had double ridges that were separated by short depression.	Differs in having distinct ridge that is rather long and wide with coarse crenulations. Shallower ventral fossa is nearly smooth throughout without any isolated raised areas bearing crenulations.
4 (patelloid structures)	On dorsal surface of RR and Brr.	Same arcuate structures as in <i>F. nobilis</i> .	Differs only in being less arcuate; lip and socket areas cover proportionally greater part of dorsal surface.
5	Between Brr.	Single dorsal ligamentary fossa restricted mainly to area of patelloid process, except on Axx; rather long "transverse ridge" near dorsal margin of articular surface; single large and shallow ventral ligamentary fossa. Crenulated margins developed only along margins that are not in contact with adjacent ossicles.	Similar to distal surfaces of RR on <i>F. nobilis</i> in lacking paired ventral fossae. Differs in having no interarticular ridge, a smooth ventral fossa without crenulated lobes or isolated raised areas, and longer, distinct "transverse ridge." Nerve openings on articular surfaces not seen, but undoubtedly some connections of the nervous system existed in all ossicles.
6	Ventral surfaces of Brr in contact with peristome.	Same corrugated appearance as in <i>F. nobilis</i> . Shape, size, and number of grooves depending on which portion of arm an ossicle belongs to. In general, ventral surface of IBrr smooth, IIBrr and IIIBrr possessing single marginal groove that runs along outer border; IVBrr with 6 to 10 small grooves, greatest number commonly in middle portion of series; more distal Brr with single ventral groove.	Similar in structure and appearance to type 6 articulations on <i>F. nobilis</i> except not found on distal surfaces of iBrr, or on lateral sides of free arm ossicles.

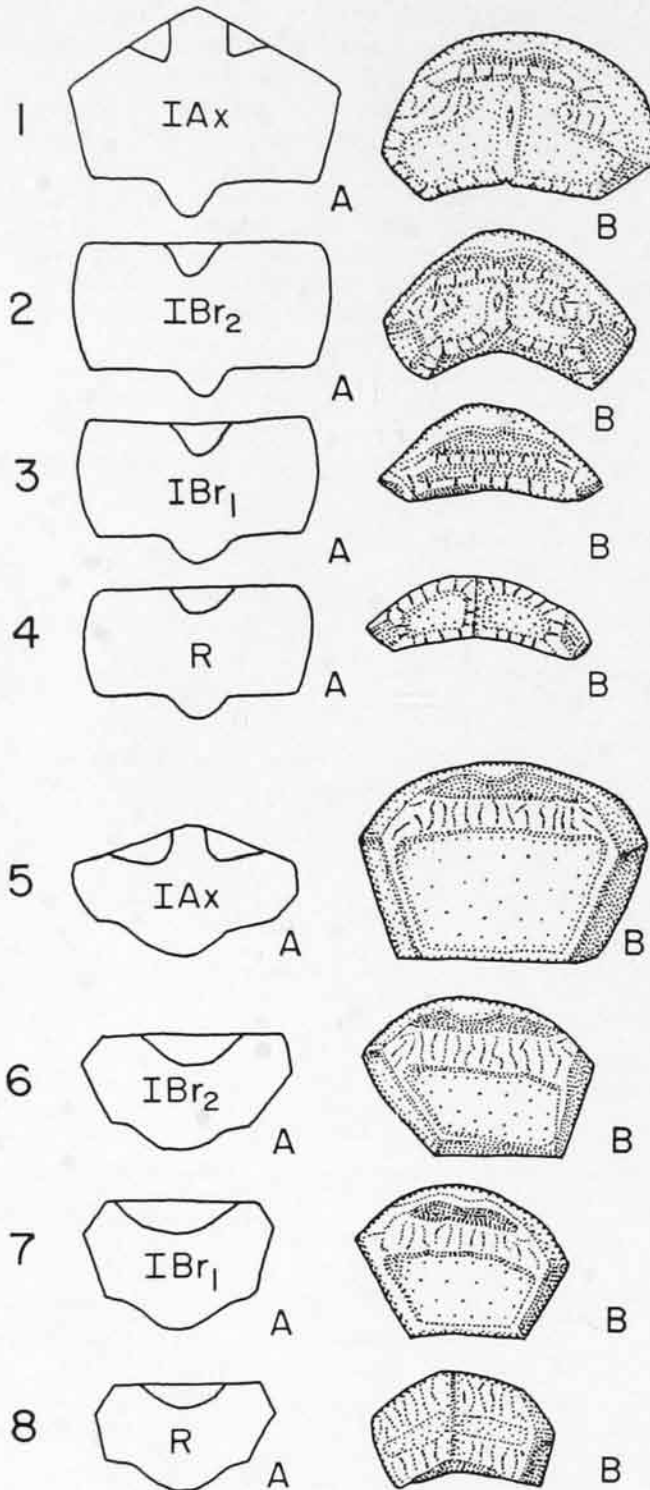


FIGURE 12. Diagrammatic illustration of radials and primibrachs of *Forbesiocrinus* and *Taxocrinus* showing relative thickness and shapes of plates.—1-4. *Forbesiocrinus nobilis*.—5-8. *Taxocrinus colletti*. [A, dorsal views, all X2; B, proximal views of articulating surfaces, those of *F. nobilis* X2 and of *T. colletti* enlarged so that

two-thirds as thick as corresponding plates of *T. colletti*. This difference not only affects appearance of the crown, but also the size of the visceral cavity in both forms. Because of thinness of plates, the visceral cavity is judged to have been much greater in *F. nobilis* than in *T. colletti*.

The relationships between radials and primibrachs are shown diagrammatically in Figure 12. The dorsal side of the plates (A) are drawn X2; however, in order to emphasize the differences in massiveness of plates in *Taxocrinus colletti*, the proximal views of this species are enlarged so that the widths of articular surfaces are approximately equal to corresponding surfaces of *Forbesiocrinus nobilis*, which have also been drawn X2.

Illustrations of the articular surfaces also indicate that besides greater massiveness, the outline of the plates is more angular than corresponding plates of *Forbesiocrinus nobilis*. By contrast, ossicles of the latter tend to have rather smooth outlines.

The mode of union between the infrabasals and stem, as in *Forbesiocrinus nobilis*, could not be observed directly. Several specimens were treated with hydrofluoric acid in an effort to remove matrix and change the composition of the shell material to fluorite. Once the shell has been converted it can be easily chipped away. With this method it is relatively simple to chip the material with dental tools so that particular structures on the articular surfaces can be traced from the surface toward the inside.

By using this method it was possible to ascertain the true nature of the proximal surfaces of the infrabasals. Between the proximal surface of the infrabasals and stem ossicles the articulations consist of rather fine radiating crenulations similar to stem symplexies but with slightly coarser culmina and crenellae. Connective tissue was not lodged in a fossa, but was confined to narrow furrows between the radiating ridges. This mode of union is judged to be nearly immovable and undoubtedly it corresponds to the same type of articulation that SPRINGER thought *Forbesiocrinus* possessed. As mentioned above, SPRINGER was unable to study this surface in his Belgian fossils, but from external appearance, he judged that it was more similar to other stem articulations than to those between other plates in the theca.

The mode of union of other thecal plates shows important differences in the two species under consideration (Fig. 13,2,3,13). The surfaces between these plates, lateral surfaces of brachials in contact with adjacent plates, and some surfaces of interbrachials are united by articulations similar to type 2 unions of *Forbesiocrinus nobilis*. However, between thecal plates of *Taxocrinus colletti* considerable differences in details can be noted.

width of articular surface is approximately equal to corresponding surfaces of *F. nobilis* ossicles. Note much greater relative thickness of plates on specimens of *Taxocrinus* and their more angular shape.]

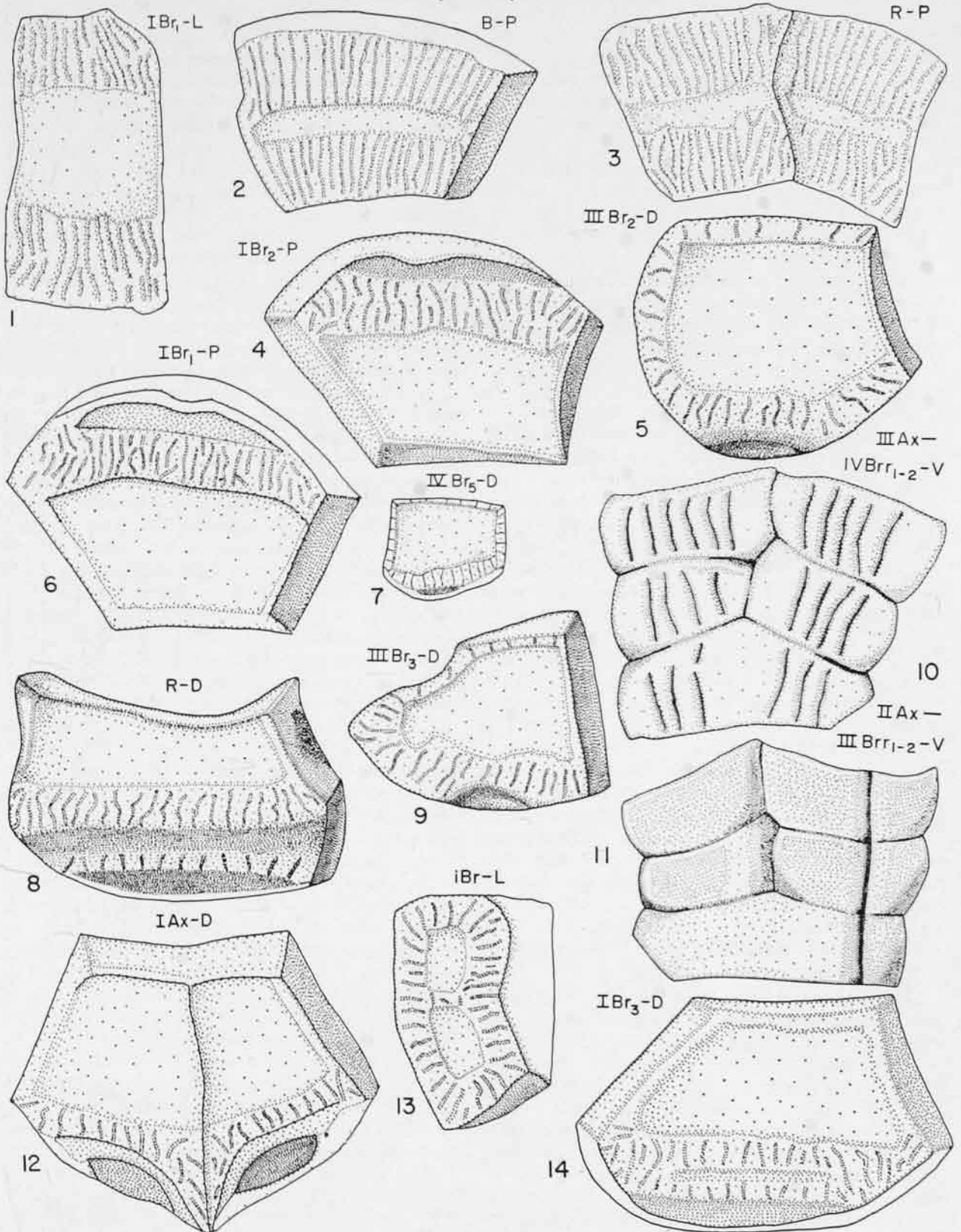


FIGURE 13. Articular surfaces on selected ossicles of *Taxocrinus colletti* from Crawfordsville, Indiana, X10. [EXPLANATION: Plate designation and orientation same as in Fig. 10.]

In this species the crenulated portions of the surfaces are better developed, and they consist of rather coarse, subparallel to irregular rows of ridges that cover most of the articular faces. Unlike corresponding surfaces of *F. nobilis*, which possess a large fossa completely surrounded by a rather thin crenulated rim, the dorsal and ventral portions of the plate surfaces in this species have well-developed long ridges. However, the lateral margins are commonly devoid of crenulations (Fig. 13,1-3). The central fossa is shallow and short, but rather wide. It extends close to the lateral margins of the plates on all surfaces, except on the interbrachials. On thecal plates it is commonly a fourth or fifth as long as the articulating surface, but on lateral surfaces of interbrachials and primibrachs it is proportionally longer. All these features clearly indicate that the theca of *T. colletti* was more rigid than that of *F. nobilis*.

The distal surfaces of the radials differ considerably from corresponding articulations of *Forbesiocrinus nobilis*. Instead of commonly having an indistinct "transverse ridge," as in the latter species, this form has a well-developed long crenulated ridge that extends completely across the surface of the ossicle, and gradually becomes longer near the lateral margins of the plates. The ventral ligamentary fossa, as on succeeding brachials, is shallow and nearly smooth. It lacks the lobed-shaped or isolated raised crenulated areas found in this fossa on specimens of *F. nobilis*. One abnormally developed radial was observed that had double crenulated ridges separated by a short deep depression (Fig. 13,8). In this specimen the first primibrach was not preserved, so it was impossible to see if the proximal surface of this plate was also abnormally developed.

Arm plates of *Taxocrinus colletti* have a patelloid structure that differs only in minor details from corresponding structures in specimens of *Forbesiocrinus nobilis*. As normally developed, it is much wider and has less arcuate downward projecting lips and sockets. This caused the dorsal ligamentary fossa to be spread over a wider area. The need for a better developed extensor ligament was undoubtedly a direct result of the more massive nature of the radials and brachials as contrasted to the much thinner plates of *F. nobilis*.

The brachials observed in specimens of *Taxocrinus colletti* are more similar to the radials of *Forbesiocrinus nobilis* in general arrangement of ridge-fossa areas than to the brachials in the latter form. Rather than having paired ventral fossae, they have only a single one. No trace of a longitudinal interarticular ridge was seen on any of the disarticulated specimens and no pits or openings corresponding to nerve canals were found; however, it is inconceivable that nerve openings did not exist on these surfaces, as some connection with the nervous system must have been present throughout the brachials.

Crenulated lobes and isolated raised areas, especially characteristic of the brachial articulations in *Forbesio-*

crinus nobilis, are entirely lacking in *Taxocrinus colletti*. These supplementary contact areas were necessary in the *Forbesiocrinus*-type surface because the outer rim areas are appreciably thinner than in *Taxocrinus*, and thus added rigidity of the plates was not needed in the latter forms.

The relatively long crenulated region that appears near the dorsal margin of the plates, and which was called the "transverse ridge" by SPRINGER, is well developed in this species. On plates attached to adjacent brachials or interbrachials the crenulated region is confined commonly to only the dorsal margin (e.g., Fig. 13,4-6,12,14). However, on brachials that have free sides, the raised margin extends around the free portion of the articulating surfaces (Fig. 13,5,9). This difference can be readily seen on examining the proximal brachials that surround the CD interray, and traces of the crenulated rim can commonly be observed even on the outer surface of the plates in well-preserved specimens. The surfaces of these brachials have crenulated lateral borders around the free portion of the ossicles, but on other rays, where adjacent plates abut against the brachials, no evidence of culmina and crenellae can be observed.

As discussed below, the ventral surfaces of the brachials differ considerably from corresponding plates of *Forbesiocrinus nobilis*. Below the tertibrachs the ventral surfaces are rather smooth and rounded, and only a single depressed groove is present longitudinally along the outer margins of the plates (Fig. 13,11). Commonly, beginning at about the axillary tertibrach, the groove splits into several narrower ones, and finally above the quartibrachs they merge into a rather large depressed furrow. These features of the brachials are especially well illustrated by SPRINGER (136), pl. 57, fig. 6c). The grooves probably represent growth lines of the calcified portion of the peristome and will be discussed further below.

Fundamental differences can be observed in the nature of distal surfaces of most upper interbrachials and in the mode of attachment of the peristome in the two compared species. In *Taxocrinus* (and also *Onychocrinus*) the upper margins of the most distal interbrachials are round and smooth, except for slight traces for attachment of peristome ossicles along the ventral margin of the plates. Marks of attachment are more readily observable on the ventral surfaces of the proximal brachials. From the primaxil, which occurs at about the same level as the most distal interbrachial plates, a longitudinal depression runs along the ventral surface of the secundibrachs nearly parallel to the lateral margin of the plates and continues along the margin of the tertibrachs. Near about the axillary tertibrach the depressed region commonly multiplies into four to ten sharply outlined grooves. In the distal portion of the quartibrachs, the grooves become reduced in number and finally grade into a relatively large median furrow. As pointed out by SPRINGER (136)

p. 231), these depressions do not seem to represent food grooves such as are found on the ventral surfaces of brachials in camerate and inadunate crinoids. As mentioned, they probably represent lines of attachment for the peristome. In mature individuals the peristome was attached to the most outer groove on the ventral surfaces of these plates (Fig. 13,10). This attachment would provide support of the ambulacra on the peristome but in this form and most other flexible crinoids, the ambulacra are not preserved, possibly because they were not calcareous or because they were separated from other parts of the specimens by decay of the leathery peristome after death. The close relationships between the singular proximal groove, supplementary grooves in the middle portion of the arms (IIIAX to IVBrr), and finally the median furrow in the distal brachials suggests that all of them served in a similar function, which was attachment for the peristome.

In *Forbesiocrinus nobilis* the peristome is connected to the arms at points beginning near the dorsal margin of the interbrachials and lower brachials and extending inward the full width of the plates. In this form the distal surfaces of the interbrachials and margins of the free arms, which are only slightly rounded, possess irregular folds or corrugations (type 6 articulations). Above the second bifurcation the corrugated lateral margins gradually diminish in thickness and finally grade into the longitudinal grooves on the ventral surfaces of the higher brachials. Relationships of this type of union are clearly seen on SPRINGER'S plates (pl. 23, 24).

As already mentioned, an entirely different mode of union occurs on plates below the distal face of the interbrachials; commonly beginning at about the middle of lateral surfaces of the second primibrachs (Fig. 10,7a). Below these points the brachials are connected with the interbrachials and these with each other by type 2 ligamentary articulations. Above the points, however, the lateral surfaces of the brachials are connected with the peristome and type 6 articulations commence, characterized by rather irregularly aligned corrugations.

ARTICULATIONS IN ONYCHOCRINUS EXCULPTUS

Apposed surfaces of certain ossicles in this species differ significantly from previously described forms, though other articulations are nearly identical. Unions between infrabasals and the proximal columnal are similar to above-mentioned forms, and those between other plates of the dorsal cup differ only in minor details. The connection of the peristome with interbrachials and brachials resembles corresponding articulations described from specimens of *Taxocrinus colletti*. However, between brachials a completely different type of union exists.

Only a few specimens of this species were available for this portion of the study, and of these only two were

properly preserved to show details of articular surfaces. Structure of the theca makes it extremely difficult to loosen the ossicles, even though the mode of union between the plates suggests that considerable flexibility existed between individual ossicles. Development of numerous interbrachials in the proximal portion of the arm region gives the specimens a rather strong thecal construction, and prevents satisfactory disassociation of the lower arm ossicles. Unfortunately, these larger plates commonly provide the best surfaces for studying brachial articulations. However, enough surfaces were examined to indicate that considerable differences existed in this form. Figure 10 illustrates diagrammatically some of the better preserved articular surfaces examined in this species.

Between dorsal cup plates, as in the two previously described species, well-developed type 1-2 articulations are common between the plates, except on the proximal and lateral margins of the infrabasals and distal surfaces of the radials. Similar faces also exist between the interbrachials and lateral sides on proximal brachials that are in contact with interbrachials. In general appearance, this union resembles that seen in *Forbesiocrinus nobilis* and *Taxocrinus colletti*, but within the fossae very irregular elevated areas which differ considerably in size, shape, and arrangement were observed. On weathered surfaces these irregular areas tend to be indistinct, but on artificially disarticulated ossicles they are well developed and appear to rise nearly to the level of the outer marginal rims. The crenulated rim is similar to corresponding surfaces in *Forbesiocrinus nobilis* in being rather thin, but unlike this Belgian form, the borders of brachials belonging to *Onychocrinus exculptus* are about the same in size around the entire central depression. The rather deep fossa and narrow rim indicate that considerable flexibility existed between these plates; however, the elevated areas within the fossae tended to provide rigidity. In some depressions the higher areas appear to have interlocked with corresponding depressed regions on apposing surfaces, but not enough ossicles could be observed to verify the occurrence of such relationships between all surfaces. Figure 14,4,6 illustrate this interlocking as seen between two apposed brachials.

The distal portions of radials and proximal surfaces of primibrachs were not observed in *Onychocrinus exculptus*. On all specimens available for study these surfaces were tightly connected, and could not be satisfactorily disarticulated. Not only were these plates firmly cemented together, but abundant development of interbrachial plates in this portion of the theca prevented separation of the proximal ray plates. One or two interbrachials connect with each lateral surface of the radials and primibrachs, respectively.

Between arm plates the articulations differ considerably from the forms previously described in this paper.

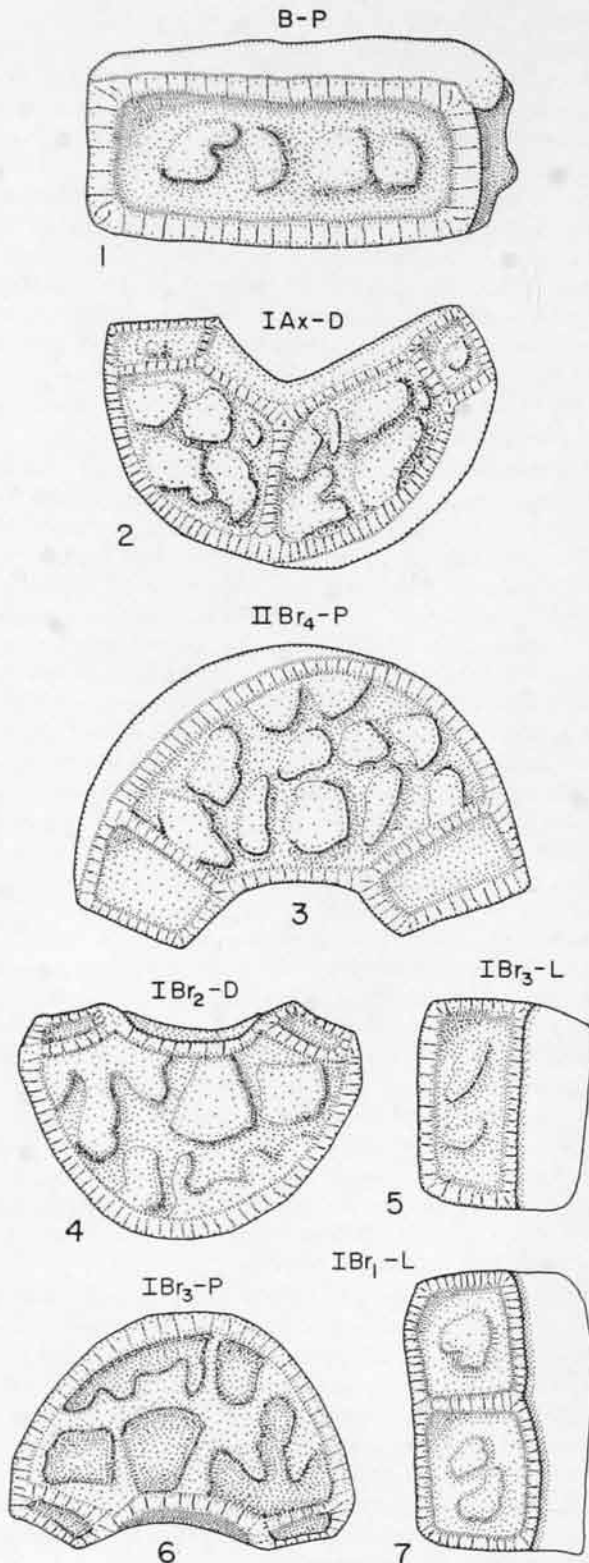


FIGURE 14. Articular surfaces on selected ossicles of *Onychocrinus exculptus* from Crawfordsville, Indiana, X10. [EXPLANATION: Plate designation and orientation same as in Fig. 10.]

The patelloid structures are commonly lacking, and only slight traces of arcuate-shaped sutures were observed between a few plates of a single individual, commonly in distal portion of arms. The absence of well-developed arcuate sutures is not, as first thought, merely the result of weathering, but was never developed between most brachials in this species. The outer surfaces of the plates are evenly convex and suture lines are distinct and continuous. Further, the crenulated rim, which appears on the surface as a zigzag line, continues directly across the plates and is not absent or reduced near the middle of the plates, as would be expected if the lip portion of the patelloid structure had been weathered. Lack of this structure greatly affects the appearance and structure of arm articulations and suggests that the mode of union in flexible crinoids was entirely by ligamentary articulations.

Only a single fossa was seen to be developed on the distal and proximal faces, and no depression corresponding to the dorsal ligamentary fossa was found on any specimens. We may conclude that the outer marginal rimmed area, which SPRINGER and others have referred to as the "transverse ridge," did not develop in this species. On all brachials observed the articulating surfaces were similar in gross form. A single large fossa occupies nearly the entire surface of the face, its depth being considerably shallower than similar depressions on dorsal cup plates. Within the fossa rather smooth elevated areas are distributed at random along the floor. No systematic arrangement of these regions was noted, and increase or decrease in number of areas could not be detected in different series of brachials. Examination of a number of such surfaces indicates that the raised areas tend to interlock with corresponding low areas on opposing surfaces. No crenulated areas, as described within fossae of specimens of *Forbesiocrinus nobilis*, were observed, and thus greater rigidity was obtained in the two species by different modifications of similar structures. In *F. nobilis* flexibility of the arms was controlled by a combination of (1) developed patelloid structures, (2) narrow but well-developed crenulated marginal rims, and (3) elevated ridge-and-furrow areas within the ventral fossae, which joined with similar structures in adjacent fossae. In *Onychocrinus exculptus*, which lacks the "lip-and-socket" structures, restricted mobility of the arms was the result of interlocking elevated regions within the fossae and by the crenulated rim. The nature and exact locations of the ligamentary tissues in these crinoids cannot be determined and it is not known whether ligaments were also present on the elevated regions of the fossae.

The complete lack of a structure resembling a transverse ridge in *Onychocrinus exculptus* seems clearly to be the result of absence of patelloid structures. Because the obliquely situated dorsal ligament that served to hold the "lip-and-socket" portion of the structures were not developed, a contact surface along the upper and

outer marginal portion of the articular surface was not required. Its absence strongly suggests that the structure in flexible crinoids called the "transverse ridge" by SPRINGER does not correspond to the ridge in inadunate crinoids which separates the dorsal and ventral ligamentary fossae and which functioned as fulcrum for differential movement.

The articulations between plates of *Onychocrinus ramulosus*, which also occurs at Crawfordsville, are very similar to those described for *Taxocrinus colletti*, except that in the former the fossae have elevated areas, as on articulating surfaces in specimens *O. exculptus*. The extremely well-developed patelloid structures on brachials of *O. ramulosus* resulted in the development of rather large dorsal ligamentary fossae and "transverse ridges." These structures, combined with the raised areas within the ventral fossae, provided extra rigidity required in this species because of the presence of very long arms, some of which exceed 15 cm. in length.

CONCLUSIONS

Data obtained in this study lead to the following conclusions concerning articulations of flexible crinoids:

1. The types of highly modified ligamentary articulations which developed in flexible crinoids are unknown in inadunates but are similar to those in some specialized camerates.

2. Except for a few species, the mode of union between plates provided considerable flexibility, as indicated by rather large, commonly deep fossae and narrow marginal borders of articular surfaces.

3. Six general types of articulations can be recognized in most forms, though in some species one or more types may be greatly modified or may be lacking. Modifications commonly resulted in increased rigidity between the plates.

4. Rigidity was accomplished by development of larger crenulated marginal rims, elevated areas within the ventral fossae possessing culmina and crenellae that interlock with similar structures on apposed surfaces, and by having raised areas within fossae interlocking with corresponding depressed areas on adjacent plates. The patelloid structures served to restrict the outward extension of the arms.

5. Increased strength of the theca not only resulted from the structures mentioned (in 4 above), but also was accomplished by development of abundant supplementary plates (e.g., abundant development of interbrachials in *Onychocrinus exculptus*).

6. Ligamentary articulations (defined by absence

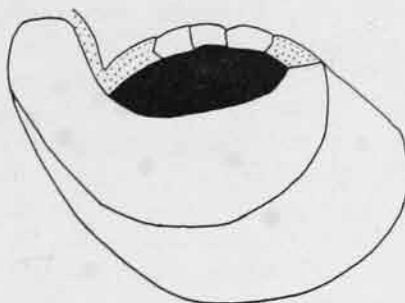


FIGURE 15. Diagrammatic representation of portion of arm of *Onychocrinus* showing relationship of peristome (stippled), ambulacral groove (black), covering plates and brachial plate. [Note area of peristome attachment near left lateral margin of brachial. Groove shown on Fig 13,11 results from this type of union.]

of a transverse ridge, which acts as a fulcrum and not merely as a raised ridge separating two or more fossae) were highly developed in most Flexibilia. No muscular articulations were developed in the three species discussed here, and it is highly probable that this mode of union did not occur in flexible crinoids. Muscular articulations are judged to have existed among Paleozoic crinoids only in the Inadunata. The development of transverse crenulated rims, which separated the dorsal ligament in forms possessing patelloid structures from the single or paired ventral fossae are judged to be in part analogous to the transverse ridges developed between brachials of some inadunates, but they were not homologous. The dorsal rimmed portion should be considered nothing more than an adaptation developed to act as the dorsal upper contact region of the articulating face.

7. The strong sutural connection between the infrabasals and proximal columnal is judged to have developed so that the dorsal cup and stem could not become easily detached and also to protect vital nerve organs housed within the infrabasal circler and proximal stem ossicles. Articulations similar to those between other dorsal cup plates would be unsatisfactory because passing organisms, debris, or even strong currents could rather easily detach the rather robust thecas from the stems.

8. Within a given species, the same types and modifications are found to be present, and thus details of these structures should be considered important morphological characters in the definition of species. However, size, shape, and arrangement of articular features, such as elevated areas of the fossae, are not identical within a species and only their presence or absence is important.

9. The true significance of articulations, as they relate to problems of taxonomy of higher taxa (e.g., genus and family-group), cannot be ascertained from the limited amount of work done in this study. Seemingly, it is possible that articulations in species representing two different genera can have more similar modes of union between plates than species within the same genus. For example, the brachial articulations of *Taxocrinus colletti* and *Onychocrinus ramulosus* are more similar than corresponding surfaces on specimens of *O. exculptus*. This is clearly because of similarly developed patelloid structure in the two forms and should not be interpreted to signify that *O. ramulosus* is phylogenetically more closely related to *Taxocrinus* than to other species of *Onychocrinus*.

CAMERATA

Study of the articulating surfaces in camerate crinoids found at Crawfordsville confirms much of the very limited knowledge about union between plates of these echinoderms and provides new data concerning their articulation. Unlike a majority of the Flexibilia, the thecal plates in most camerates were united by very short fibers of connective tissue and rarely the plates are ankylosed. Except for a few genera, so-called "close-sutural" union provided a rigid theca and this feature is one of the most fundamental characteristics of this group of crinoids.

Considerably fewer camerate specimens were available for this phase of my study than were available for the Flexibilia, and thus articular surfaces of all camerate species found at Crawfordsville and commonly various surfaces occurring between plates of a single species could not be examined. Because of this, the types of unions observed between different types of ossicles (radials, brachials, etc.) are discussed separately, using several species as examples.

Individuality of the plates remains well defined in a majority of forms because it was along the outer surfaces of the plates that growth occurred and rigidity of the theca could be produced without fusion of plates. Complete ankylosis of thecal plates would tend to retard growth in most forms, and thus this feature is most commonly developed after maximum growth was attained. As seen from study of Recent crinoids, the ability of these organisms to precipitate calcareous material is extraordinary, for particles of calcium carbonate in the form of spicules or heterogeneous bodies can be deposited almost anywhere.

The formation of this supplementary material is particularly abundant wherever the connective tissue is not occupied by regular calcareous material, and it may be developed both externally and internally.

Complete or partial fusion of dorsal-cup plates is known to occur in some crinoids, for example, the Recent articulate *Holopus* and the aberrant Paleozoic genus *Edriocrinus*, which is questionably assigned to the Flexibilia. In some species fusion is restricted to only certain circlets or areas of the crown. In the Crawfordsville species *Platycrinites hemisphericus*, the basals are commonly ankylosed, regardless of age of individuals; some species of *Dichocrinus* in which pendent arms are developed, have fused proximal brachials which form a more rigid support for distal portions of the arms. In species in which fusion occurred before skeletal growth ceased, increase in size of plates seems to have been made possible by partial or complete resorption of material responsible for the fusion. After plates reached a certain size, growth would temporarily cease and deposits of supplementary material would fuse the plates. Before further growth could occur, this secondary material would have to be resorbed. It seems unlikely that increase in size of plates could occur while plates were fused together. According to WILSON (170, p. 503), the mechanism necessary to permit continuation of growth in forms with fused plates could be provided by absorption of calcium carbonate by amoeboid cells that ". . . take calcareous salts into absorption and transmit them to depositional cells." This process results in resorption of the entire anal and oral plates in the living crinoid *Antedon*, and seems to be the most likely known process to account for abnormal development in some plates of Paleozoic crinoids (SPRENG & PARKS, 129, p. 594).

Most thecal ossicles of camerate crinoids are united in such a manner that only slight movement, or none at all, occurred between the plates; these unions are called immovable articulations. On apposed surfaces of most cup plates in Crawfordsville camerate crinoids studied the joint faces are smooth and flat. Such surfaces with little or no concavity are typical of zygostostial articulations, and these probably are the most common type of unions developed on the dorsal cup plates of nonflexible Paleozoic crinoids. Some surfaces may be ornamented with thin striations, irregular vermiculations, or rather coarse subparallel crenulations, which on exterior surfaces appear as denticulations. Others developed rugosities

that conform to no particular patterns. In the majority of specimens observed only a single type of ornamented surface was found between all plates of the dorsal cup (except on distal surfaces of radials in a given species. However, many species of different genera have similar-appearing articular surfaces, and thus mode of union between these plates cannot be considered significant taxonomically. Only rarely (e.g., *Platycrinites hemisphericus*) does more than one type of union occur between cup plates.

In Crawfordsville specimens studied, the most common type of union consists of smooth flat surfaces in which no irregularities or ornamentation can be seen. This type was observed between dorsal cup plates (except distal surfaces of radials) on all batocrinids, as well as in species of *Agaricocrinus* and *Gilbertsocrinus*. In *Paradichocrinus*, which is characterized by very thin plates, the surfaces of apposed thecal plates are rather rough and at places vermiculate. As in most other camerates, the articular surfaces are nearly flat. Undoubtedly, rugosity of the surfaces provided more rigidity to the cup plates. In other forms, especially in some genera of batocrinids (e.g., *Abatocrinus*, *Dizygocrinus*) and others (e.g., *Agaricocrinus*, *Gilbertsocrinus*), thickness of the plates alone induced rigidity and irregular or ornamented articular surfaces were not needed to effect skeletal immobility.

The most variable modes of union between cup plates of camerates that were observed occur in specimens of *Platycrinites hemisphericus*. The majority of individuals have plates of the basal circlet ankylosed; however, between the basals and radials and between the latter plates, well-developed coarse crenulations occur, oriented parallel to the longitudinal axis of the joint faces. Most crenellae are nearly straight, separating similarly shaped elevated regions of about the same width, but some appear irregular or branched. On the exterior of well-preserved specimens traces of these articulations appear as denticulations. Again, the relative thinness of these plates indicates that modification of the more typical smooth surfaces was developed to provide greater rigidity to the dorsal cup.

Although articular surfaces of cup plates just discussed suggest that little or no mobility existed in the lower part of the camerate crown, some forms (not found at Crawfordsville) have well-developed flexible articulations. Prime example of this modified type of camerate union is the genus *Scyphocrinites*,

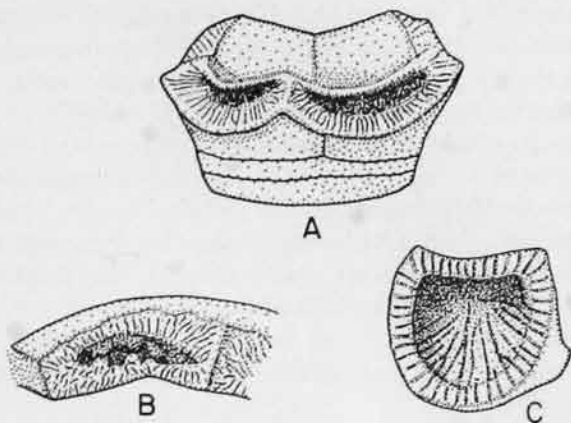


FIGURE 16. Union of plates of *Scyphocrinites* (camerate) showing well-developed fossae and crenulated outer margins that resemble some species assigned to *Flexibilia*, all X4.—A. Distal surface of basals.—B. Distal articulation of secundibrach.—C. Proximal articular surface of radial (135).

of Silurian and Devonian age (SPRINGER, 135, p. 19), in which a narrow, commonly continuous and crenulated rim surrounds a ligamentary fossa. The articulating surface of each plate is crenulated, with subparallel ridges originating in the deepest portion of the fossae and radiating outward to outer margins of the plates. This type of union provided considerable mobility, and in general appearance it resembles some of the surfaces observed on apposed articular surfaces of flexible crinoids. Without question, however, these articulations developed independently in the two forms. In *Scyphocrinites* the distal surfaces of the basals have a single, deep, inward-sloping fossa, and the apposed proximal facets of the radials have corresponding deep depressions, with floors divided into irregular pits, from which culmina and crenellae radiate. Between brachials the articulations are also different from those typical of most other camerates (described below). Separating the primibrachs, proximal secundibrachs, and interbrachials, a series of elongate corrugations are developed, oriented normal to the longitudinal axis of the plates. They consist of very narrow fossae and rimmed crenulated margins. Along the inner margins of the plates a rather long continuous inner rim occupies nearly the entire width of the plates. Between the distal secundibrachs and tertibrachs single, deeply inward-sloping fossae are surrounded by broad crenulated borders. Distally, the fossae become less distinct, although the crenulations remain well developed. Figure 16 diagrammatically illustrates some of these surfaces, providing

comparison between this highly modified type of camerate articulation and more typical ones occurring in the Camerata. Although its thecal joint surfaces resemble those of *Forbesiocrinus*, *Scyphocrinites* is not closely related to any known flexible crinoid. Other camerate genera (e.g., *Glyptocrinus*, *Reteocrinus*) have well-developed flexible articulations, but these unquestionably also belong to the Camerata, and as far as known, are not closely related to any crinoids assigned to the Flexibilia. Thus, it is apparent that flexibility, resulting from similarly developed articulations, can occur independently in different subclasses of crinoids.

Fixed brachials, like other plates in the dorsal cup, are united to each other and with adjacent plates by zygosynostosal articulations. In all specimens observed, details of these unions resemble other surfaces between cup plates, except the most upper face of the distal fixed brachials, which bear the free arms. These arm-bearing articulations are commonly the most well-developed surfaces occurring between brachials, and suggest that maximum mobility occurred in the proximal portion of the arms.

In most forms with fixed brachials, the arm-bearing facet is more or less concave, commonly smooth or with thin striations, vermiculations, or weakly developed oblique ridges that are not continuous across the plate. The concavity suggests presence of relatively well-developed ligamentary tissues between these plates. Commonly between more distal brachials the concavity becomes much less distinct, and thus it is judged that in this portion of the arms in many camerate species proportionally much less connective tissue was present.

Examination of numerous published illustrations (e.g., WACHSMUTH & SPRINGER, 159, pl. 36, fig. 76; pl. 39, fig. 2, 3; pl. 41, fig. 1-4; figures on pl. 54, 57, 74, etc.; also WANNER, 160, pl. 98, fig. 7; pl. 99, fig. 1, 9, etc.) indicates that major movement of the arms in many camerate species was in a lateral direction, rather than dorsoventrally, which is typical of most inadunate and flexible crinoids. Lateral movement is particularly noticeable on forms in which two separate plates form a compound arm facet, but also probably was present in forms in which biserial arm plates were present in proximal portions of the arms. GISLÉN (37, p. 66) termed these unions synarthries because of their superficial resemblance to synarthrial articulations present between plates of many post-Paleozoic crinoids and between stem ossicles in forms such as *Platycrinites* and *Bathycrinus*; however, these

articulations in camerates have an entirely different structure, although, as with true synarthries, they indicate that major movement was in two directions. On true synarthries a central ridge separates two rather large hemispherical ligamentary areas developed on a single articular surface. On camerate joint faces the ridge is commonly not developed, but a dorsal overlap of plates occurs in forms having compound articulations. Thus, rather than functioning as one articulating facet, the ligamentary areas are developed alternately from one side to the other, along the length of the biserial arms in forms such as *Agaricocrinus* and *Alloprosallocrinus*. In camerates with only a single plate bearing the arms a uniserial plate commonly forms the initial brachial, although next higher brachials immediately become biserial; however, arms have been observed that are biserial for their entire length (Fig. 36).

The synarthrial type of articulation found in camerates may be designated more accurately as *pseudosynarthry* (false synarthry) because, while allowing movement in two directions (lateral) as in true synarthry, it lacks distinct central ridges and commonly is formed by two alternating ossicles. As discussed previously, a *cryptosynarthry* (hidden synarthry) is one in which the fossae are weak and indistinct, and found between plates in some post-Paleozoic crinoids. These two terms, although similar, should cause little confusion, because they properly suggest the nature of the two modified synarthrial types of articulations and the meaning of the prefixes is evident.

Joint faces between fixed-brachials and free arms in the Crawfordsville camerates studied can be divided into three general types. Defined by number and kinds of plates that support the arms, these include (1) articulations borne on the uppermost single fixed-brachials (e.g., *Abatocrinus*, *Dizygocrinus*, *Macrocrinus*, and most other camerate genera); (2) those in which two separate plates each bear half of what may be termed a compound arm facet, although ligamentary areas probably operated as separate units that alternated from one side to the other (e.g., *Agaricocrinus*, *Alloprosallocrinus*); and (3) atypical camerates that possess dorsal cups resembling inadunates, because fixed-brachials are absent and thus the free arms are supported directly by the radials (e.g., *Platycrinites*, *Dichocrinus*, *Paradichocrinus*). Figure 17 illustrates examples of these unions selected from specimens of the Crawfordsville material.

Forms in which the free arms are borne on a single fixed-brachial are most abundant. Probably they permitted more dorsoventral movement than in forms with compound facets. On surfaces observed in this

study the facets are only slightly concave and generally smooth. On the surface of several arm-bearing plates of specimens of *Dizygocrinus montgomeryensis* three or four small, indistinct depressions were ob-

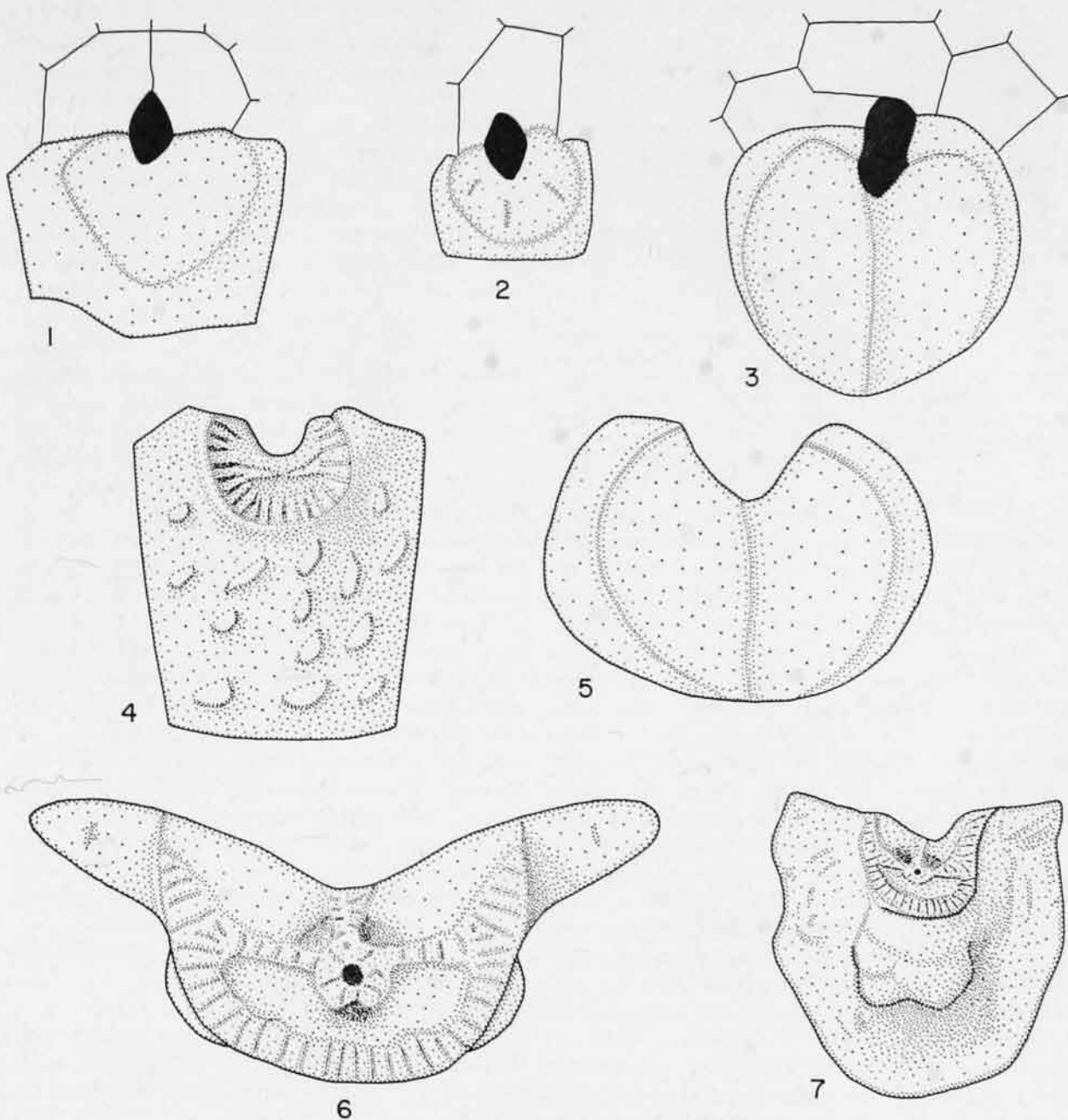


FIGURE 17. Arm-bearing articular facets of selected camerates found in the Crawfordsville crinoid beds.—1. *Abatocrinus grandis*, X8.—2. *Dizygocrinus montgomeryensis*, X6.—3. *Agaricocrinus americanus*, showing compound arm facet, X7.—4. *Platycrinites hemisphericus*, radial facet, X3.—5. *Alloprosallocrinus conicus*, showing compound arm facet, X5.—6, 7. *Paradichocrinus polydactylus*; 6, distal articular surface of radial facet, X6; 7, slightly oblique view of radial showing relationship of the facet to the large protuberance on the outer surface of the plate, X3.

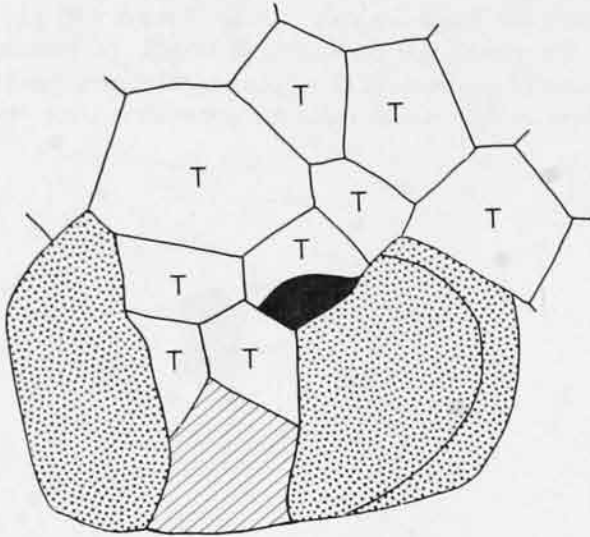


FIGURE 18. Part of crown of specimen of *Alloprosallocrinus conicus* with left half of compound arm-bearing facet removed (lower center of diagram) showing relationship of most proximal brachial with underlying plates, X5. [EXPLANATION: Brachials stippled, arcuate portion of underlying fixed-brachial diagonally ruled, plates of tegmen designated by "T," and black area near center of diagram representing ambulacral groove.]

served. The apposed proximal surface of the next higher brachials was not preserved; however, it is probable that on these facets corresponding ridges fitted into grooves on the arm-bearing facet. On most distal surfaces of other species of *Dizygocrinus*, as well as other batocrinids having this type of union, the facets are smooth, without observable structures.

Camerates having compound arm-bearing facets are characterized by very large surfaces for the attachment of arms. Near the distal portion of the dorsal cup next lower fixed-brachials commonly become arcuate, and bend distally. As observed on specimens of *Alloprosallocrinus conicus*, the surface of plates supporting the arms is lodged so that it overlaps part of the distal arcuate portion of the next lower fixed-brachial and the proximal tegmental plates by zygosynostiosial unions. This relationship is shown diagrammatically on Figure 18. In the illustration the left half (center) of a compound facet has been removed to show its relation to underlying ossicles. In all observed specimens having compound arm-bearing plates, the facets consist of subequal hemispherical areas, which are distinctly concave and smooth. On specimens that have been disarticulated or those in which the arms are not preserved, a distinct transverse ledge, representing the inner margin of one plate, is considerably higher than the adjacent plate of the same

facet. This relationship indicates that each hemispherical ligamentary area operated separately and alternately along the arms, resultant movement being almost entirely restricted to lateral directions. This is in sharp contrast to the mechanism of articulations borne on a single arm-bearing facet.

Camerates in which the free arms are supported by the radials represent a polyphyletic group of crinoids, now placed in several well-defined families that tended to develop arm structures more typical of inadunates than other camerate forms possessing fixed-brachials. In species that have these plates the fixed-brachials represent the proximal portions of free arms in larval stages that have been subsequently incorporated into the dorsal cups of mature individuals. Invariably these plates are uniserial in arrangement and branch dichotomously. Camerates that do not have primibrachs fixed in the dorsal cup (e.g., platycrinids, hexacrinids, dichocrinids, etc.) undoubtedly retained the typical larval arrangement of the arms because incorporation of the brachials into the cup was prohibited by excessively large radials and the comparatively small size of brachials. It is interesting to note that, geologically speaking, this group of camerates outlasted most forms possessing fixed-brachials. Thus, the most successful group of camerates were forms that departed least from the inadunate type of crown.

Two quite different types of radial facets were observed on specimens from Crawfordsville that have free primibrachs. *Platycrinites hemisphericus* possesses deeply concave radial facets that slope distinctly in an outward direction. Well-defined crenulations arranged along the outer margin of the facet extend into the inner concave ligamentary area, which is commonly smooth, and little depressed. Ventrally a slight ridge is developed that narrows near the center of the joint face. In some specimens the subcentral ridge consists of two separate elevations that are separated in the center. Behind the ridge a single, rather large fossa occurs. Examination of this facet, shown diagrammatically in Figure 17,4, indicates that major movement was outward rather than laterally, as in groups discussed above. The exterior distal portion of the radials would tend to prohibit lateral movement, at least in the most proximal portion of the arms.

The radial facet of specimens of *Paradichocrinus polydactylus* is different, although it superficially resembles those of *Platycrinites hemisphericus*. On the external surfaces of each radial a prominent protuber-

ance is developed along the central part of the plate. Near the proximal portion of the radials it may be narrow and thin or not developed, but distally it becomes wide and greatly thickened into a flat upper surface, which bears the arms. As in *Platycrinites*, the marginal edge of the radial facet is crenulated, but the furrows are commonly slightly less distinct. The outer two-thirds of the articular facet is flat and the inner portion slopes upward slightly. Unlike forms that possess outward-sloping faces, major limited movement of the arms of *Paradichocrinus* was not restricted to two directions, but occurred in several. Disarticulation of the arms revealed that on the radial facet three distinct ligamentary fossae are developed, each separated by a narrow crenulated ridge. The single dorsal fossa has a nearly smooth floor except near the upper central portion of the ligament area where a distinct pit occurs. In the two ventral fossae, similar but less distinct pits also occur against the weakly developed longitudinal ridge, which separates the two ligament areas, and the raised central portion of the radial facet surrounding the nerve opening. The three pits are judged merely to represent areas of greatest development of ligamentary tissues, rather than separate articular structures. In all specimens, they are associated with large depressions that clearly represent ligamentary fossae.

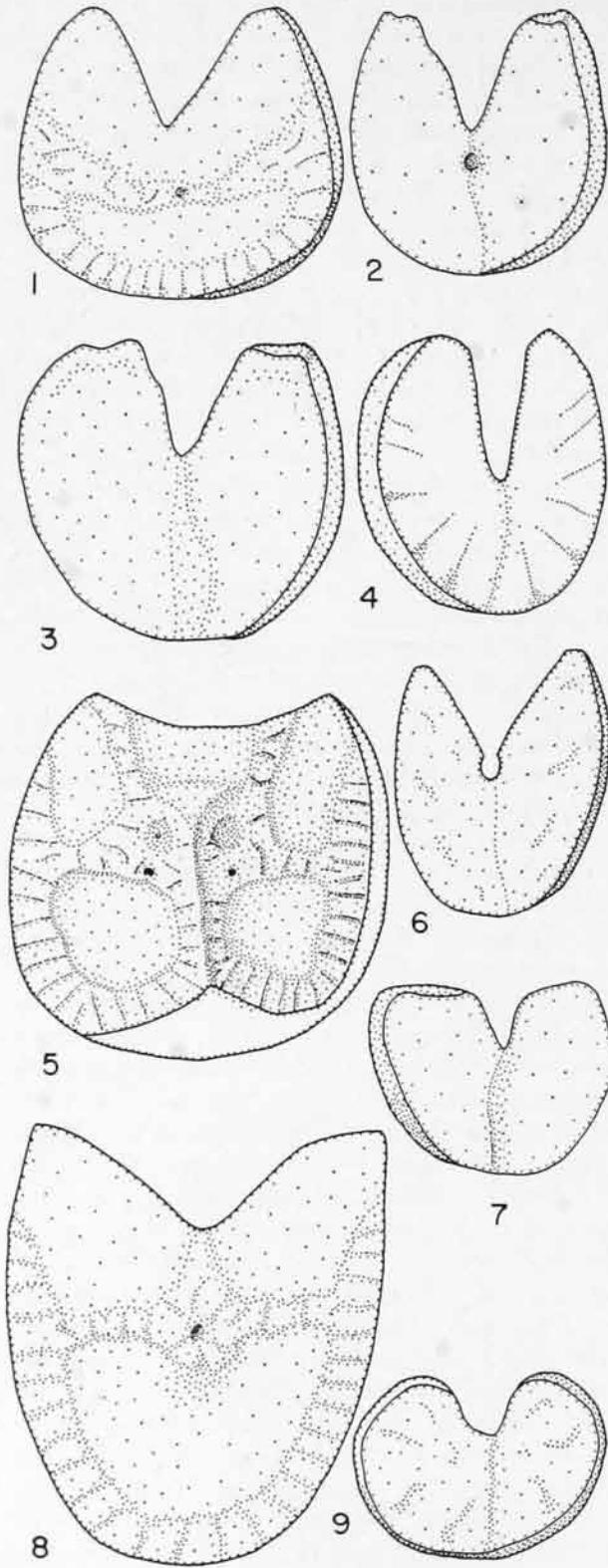
Articular surfaces between brachials of most camerates studied from Crawfordsville are commonly smooth and nearly flat. The synostiosal unions suggest that little or no movement occurred between the plates; yet, the distal portion of the arms is commonly curved inward, and some forms have spreading arms, which suggest that some mobility existed. UBAGHS (150, p. 704) stated that greater flexibility was achieved in some forms merely by multiplication of plates, rather than by development of true articular structures, and he cited *Desmidocrinus* as a prime example of this condition. Specimens of this desmidocrinid genus have 60 to 70 sutures per cm., but the maximal number observed on batocrinids from Crawfordsville were considerably smaller (30 to 40 per cm.).

Except atypical camerates, such as *Scyphocrinites*, which developed flexible articulations, most Camerata that possess modifications of simple zygosynostiosal unions added structures that increased rigidity of the arms. These supplementary structures, consisting of thin radial striations, rather coarse radial crenulations, irregular vermiculations, or oblique ridges that interlocked with corresponding grooves on apposed articular surfaces, tended to restrict movement. Figure

19 illustrates some of the articulations observed between arm ossicles of specimens studied from Crawfordsville. The majority of species showed no structures on these surfaces and the unions were nearly flat, rather than concave. This condition indicates that ligamentary tissues were weakly developed, and thus served only to connect apposed brachials. They did not allow appreciable arm flexibility.

Exceptions to this prevailing condition were observed on surfaces between proximal uniserial brachials in forms in which the radials bear the free arms. These arm plates have well-developed ligamentary structure, such as those shown diagrammatically in Figure 19,1,5,8. On the distal joint face of the first secundibrach in specimens of *Paradichocrinus polydactylus*, three distinct ligamentary areas occur in normal arrangement, that is, a single dorsal fossa and two ventral ones. Instead of six ligamentary depressions that would be expected on axillary plates, the distal surface of the primaxil in this species has five fossae. Only a single fossa was observed in the inner central region on three different primaxils that were successfully disarticulated from the arms. This arrangement is different from any other articular facets seen, and indicates that the two inner ventral fossae must have coalesced, so that now this area appears as a single ligamentary area, instead of a paired one. Thus, this fossa shares its antagonistic function with both left and right dorsal extensor ligaments. The presence and outlines of the five fossae suggest that oblique dorsoventral movement prevailed in this portion of the arms, rather than dorsoventral or lateral movement characteristic of more typical forms. As in other camerates, the proximal biserial portions of the arms in these specimens have smooth, nearly flat articulating surfaces, which indicate that practically no movement occurred between these plates.

Between uniserially arranged brachials in specimens of *Platycrinites hemisphericus* two somewhat weakly developed ligamentary fossae are present, and on the distal surfaces of the axillaries are four well-defined fossae. The dorsal ligamentary areas are commonly smaller but more distinct, and completely surrounded by crenulations. However, the more ventral raised rim, which separates the two fossae is much narrower and less well defined. In the large ventral ligamentary areas the margins are less distinct and culmina with crenellae are present only on the dorsal side of the fossa (Fig. 19,1). As observed on several specimens of this species, the articular surfaces



become less distinct between more distal brachials. The initial biserially arranged arm plates and all subsequent ones have almost flat, smooth joint faces. Thus, greatest mobility of the arms occurred in the more proximal uniserial portion of the arms, decreased rapidly in the distal uniserial portion, and was practically nonexistent between more distal biserial arm ossicles.

Some batocrinids (e.g., *Dizygocrinus*, especially *Eretmocrinus*) tend to develop flattened distal arm extremities. This portion of the arms lacks ambulacral grooves and commonly exhibits ankylosed sutures. Some species of *Eretmocrinus* have serrate outer margins that interlock at the edges, forming a solid roof over the tegmen. These modifications seem to be an attempt, at least in part, to solve the so-called sanitation problem that developed in crinoids in which the tegmen was completely surrounded by arms. In these forms, long well-developed anal tubes are invariably present, serving to extrude waste matter above the arms and prevent fouling of the lower exposed ambulacral grooves. The development of a rooflike structure would provide additional protection from the settling of waste matter.

One of the most pronounced evolutionary trends among camerate crinoids is the development of increasingly numerous pinnules in unit distances along the arms. This trend was accomplished by the shortening of uniserial brachials and change in overall shape of the arm ossicles to short wedge-shaped plates. Maximal number of pinnules was achieved in forms with biserial arms, and these represent a culmination of arm development. Within some Paleozoic crinoid groups (e.g., dicyclic inadunates and camerates) development from uniserial brachials to closely spaced biserial pinnulate arms can be readily traced. Undoubtedly the increase in number of pinnules resulted in greater efficiency of food-gathering processes, as well as increased efficiency in respiration, and support for functional portions of the genital organs, which are thought to have been associated with pinnules.

FIGURE 19. Articular surfaces on distal faces of brachials of camerates from Crawfordsville, Indiana.—1, 2. *Platyerinites hemisphericus*; 1, distal first tertibrach; 2, more distal brachial, both X20.—3. *Agaricocrinus splendens*, X16.—4. *Abatocrinus grandis*, X20.—5, 6, 8. *Paradichocrinus polydactylus*; 5, distal surface of primaxil, X6; 6, distal brachial, X9; 8, surface of first secundibrach, X6.—7. *Dizygocrinus montgomeryensis*, X16.—9. *D. indianaensis*, X20. [All brachials are biserial except 1, 5, 8.]

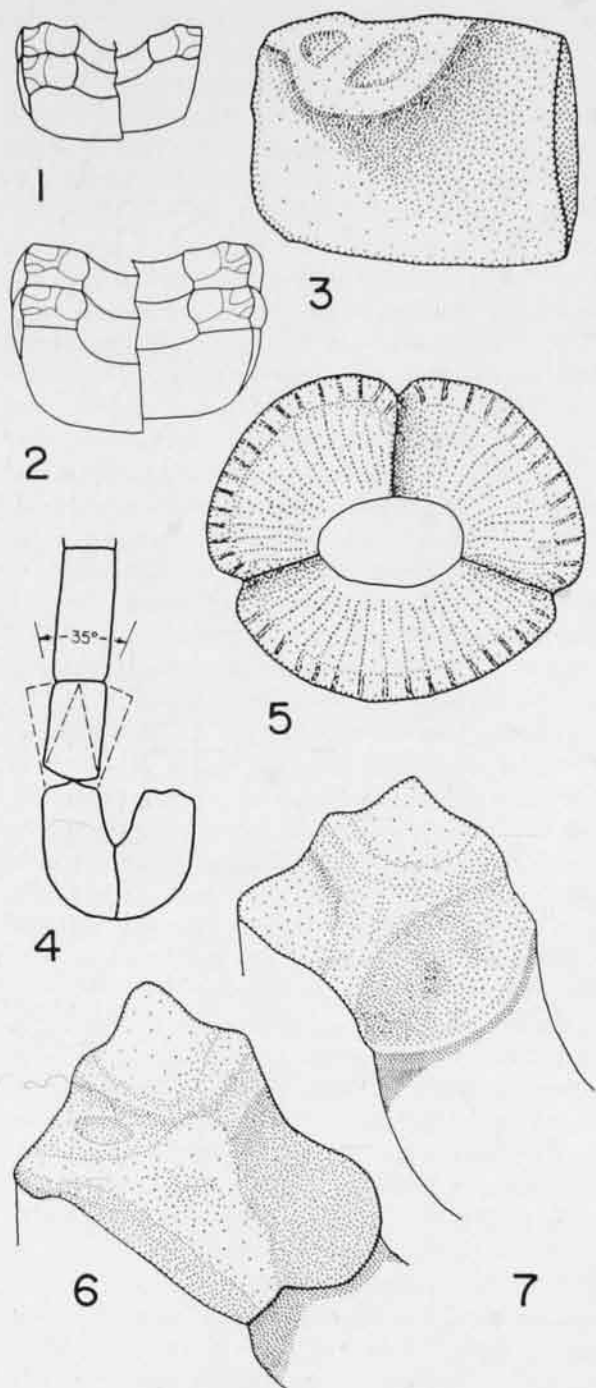


FIGURE 20. Brachial articulations for attachment of pinnules and structure of tubular appendages of *Gilbertocrinus tuberosus*, judged to represent hypertrophy of pinnules.—1, 2. Schematic oblique view of a portion of arm ossicles on *Dizygocrinus indianaensis* and *Agaricocrinus splendens*, respectively, showing relationships between articulations and food grooves.—3. Simple two-fossae articulation for pinnule attachment of *Ctenocrinus aculeatus*, Devonian of Belgium, X60 (after Ubaghs, 1945b).—4. Theoretical direction and amount of movement of pinnule based on height and location of ridge and outer border of ligament fossae.—5. Union be-

Only a very limited amount of knowledge has been published about the morphology and mode of union of pinnules with arm plates, which is not surprising in view of the delicate nature of structures that are easily destroyed by compaction and other diagenetic processes. Most recently, UBAGHS (148, 150) has contributed new and important data, but like most previous studies, these have not been concerned with post-Devonian genera. Data obtained from disarticulation of several well-preserved specimens from Crawfordsville indicate that different types of articular surfaces exist between arm ossicles and proximal-most pinnulars in these forms, and they represent more advanced types of unions than have been observed in previously described pre-Mississippian species. Thus, it seems that greater efficiency was not only accomplished by development of more numerous pinnules in a unit distance along the arms, but also by more complicated and advanced types of articulations between arms and the pinnules.

Unlike the nearly immovable unions between biserially arranged brachials, the articulating surfaces of the arm plates and first pinnulars represent a well-developed antagonistic system that indicates proportionally much more mobility between these plates than between brachials. Greatest movement occurred in an oral-aboral direction, which is normal to the longitudinal axis of the arm plates; however, as shown by UBAGHS (1945b, pl. I, fig. 6, 7), in some forms oblique movement may occur, depending on orientation of the facet. The basic structure of the pinnule-bearing surface of the brachials that he described in Devonian genera (*Ctenocrinus*, *Acanthocrinus*, *Diamenocrinus*) consists of two fossae separated by an elevated transverse ridge (Fig. 20,3). The articulations in these forms are not fixed in position or orientation.

The corresponding facets of specimens from Crawfordsville available for study are more advanced and have three well-defined ligamentary depressions, as well as a constant orientation. The pinnule-bearing surfaces of specimens of *Dizygocrinus indianaensis* have facets that cover the entire surface (Fig. 20,1,7). Two small, somewhat indistinct outer ligamentary fossae are separated by a raised area that bifurcates adorally. On the inner portion of the facet a large oval-shaped depression, which slopes rather steeply

tween distal portion of a singular tubular appendage on *G. tuberosus*, X10.—6. Pinnule attachment on brachial of *A. splendens*, approx. X55.—7. Similar surface, but more complex, on brachial of *D. indianaensis*, approx. X65.

toward the oral groove of the brachials, is developed. The general orientation of the raised areas are the same, and the two outer fossae are nearly equidimensional on all surfaces observed.

The presence of two outer fossae, instead of a single one as described by UBAGHS suggests that in this form, more advanced type of pinnular union has developed. The equidimensional outer fossae indicate that predominant movement was oral-aboral, but some oblique movement could possibly have been accomplished by one outer ligament contracting more (assuming that these ligaments had some contractile power). If oblique movements were dominant, then it is reasonable to assume that the adjacent outer fossa would be reduced, but this condition was not observed in this species.

Articular surfaces for attachment of proximal-most pinnulars on specimens of *Agaricocrinus splendens* have the same general three-fossae pattern, but in detail they are much more complicated (Fig. 20,2,6). The lower portion of the articular face, when viewed orally, and so that distal brachials are up, consists of a rather high-raised area that extends completely across the side of the brachial. Thus, the actual ligamentary areas are confined to the distal half to two-thirds of the arm face, depending on length of the proximal raised area. The elevated region restricted lateral movement of the pinnules, prevented them from interfering with movements of adjacent ones, and protected the ligaments. The ligamentary areas were separated in a proximal direction by a ridge that occurred on the same plate, and distally by the elevated area occurring on the adjacent next-higher brachials. On the distal outer edge of the raised area is a small but very distinct fossa that is one of the most conspicuous features of the articulation. Its small size probably results from at least partial restriction in movement in this direction caused by the proximal ridge. Distally, along the outer edge, another outer ligamentary fossa is found. Its boundaries are much less distinct but it is much larger than the other outer fossa. Because of its size and position, it probably served as the main antagonist to the large crescent-shaped inner ligament. These two fossae, as well as areas between the outer ones, are separated from each other by narrow, distinct ridges. Invariably the ridge separating the inner and outer fossae is better developed. Development of fossae on these surfaces indicates that direction of movement was dominantly transverse to the longitudinal axis of the brachials, and slightly oblique in an upward direction.

Amount of movement that a pinnule was capable of achieving cannot be determined accurately because the nature and amount of ligamentary tissue that was present cannot be determined. However, the maximal amount possible is largely a function of height and location of the ridge separating the ligamentary fossae and the length and slope of the fossae (Fig. 20,4). For example, maximal inner movement would occur when the inner surface of a brachial plate was in contact with the inner edge of the first pinnular. This, of course, would depend on the amount of ligamentary tissue developed in the inner fossa and the flexibility of the antagonistic tissues. Between successive pinnulars probably little or no movement occurred, at least in the specimens studied from Crawfordsville. The apposed surfaces are smooth and flat, with no observable supplementary structures.

Pinnules of many crinoids become greatly modified so that in function, position, and appearance they may bear little resemblance to normal ones that branch from the arms of most crinoids. This tendency to diversification is best seen in some Recent crinoids in which the pinnules have become differentiated into three types: proximal oral pinnules lacking ambulacral grooves and podia that function as tactile and protective structures; short genital pinnules, which support the gonads; long, slender, distal pinnules with ambulacral grooves and podia. This type of differentiation is unknown in Paleozoic crinoids; however, different pinnular modifications are found to occur. For example, the Silurian camerate *Barrandocrinus* has both immovable and free pinnules, and in *Glyptocrinus* and *Scyphocrinites* the proximal pinnules are commonly incorporated almost completely into the dorsal cup. This tendency of some pinnules to undergo development completely different from more typical ones led SPRINGER (135, p. 44-46) and UBAGHS (150, p. 702) to suggest that the robust tubular appendages of *Gilbertsocrinus* were derived by the hypertrophy of certain pinnules. The origin of this structure is discussed in more detail below (*G. tuberosus*, p. 104), but new data concerning the mode of union between ossicles comprising the appendages are included below.

In Burlington species the tubular appendages are composed of circular undivided ossicles, which resemble columnals in appearance, and according to SPRINGER (135, p. 45), in mode of union between the plates. Keokuk forms, such as *Gilbertsocrinus tuberosus*, have divided plates, so that appendages are composed of a single large dorsal ossicle and two

smaller ventral ones. Thus, instead of appearing as stem ossicles, the plates of these forms more closely resemble pinnules and arm segments, but this is only superficial, because the plates alternate and in detailed structure resemble neither brachials nor covering plates.

On the exterior surface of well-preserved specimens the sutures between plates appear denticulate, but instead of interlocking, as between stem ossicles (symplexies), the raised areas meet corresponding structures on adjacent faces. Along the outer margin the culmina and crenellae are somewhat more distinct. The inner portion of the articulation appears slightly lower, but this is not judged to represent a separate ligamentary fossa because most ridges and furrows can be traced inward. Therefore, ligamentary tissues probably covered the crenellar grooves on the entire articular surface. The radially arranged culmina and crenellae are more similar to syzygies between brachials than to interlocking symplexies between stem ossicles, and they suggest that a limited amount of movement was possible in all directions. Although no Burlington species were studied, these forms probably also had similar types of unions and were not, as SPRINGER implied, composed of interlocking symplexies. Figure 20,5 illustrates diagrammatically articular surfaces of a distal single tubular appendage.

CONCLUSIONS

Based on my study of articulations between plates of camerates occurring at Crawfordsville, the following conclusions concerning mode of union in this group of crinoids can be made.

1. Zygosynostosal unions occur between dorsal cup plates, and in most forms apposed articular surfaces are smooth and flat. This indicates that the dorsal cups were rigid. Supplementary structures, when present, added greater rigidity rather than flexibility, and presence of them seems to be closely related to thinness of the plates. Several camerate genera (not found at Crawfordsville) developed highly flexible dorsal cups with distinct fossae and crenulated rims. These forms have articulations that closely resemble those described above, occurring between plates of certain species of *Flexibilia*; however, other features of these camerates do not suggest that they are closely related. Thus, similar appearing and probably functioning articulations can develop in different subclasses of crinoids.

2. Except in species that show tendency toward

ankylosis of certain plates, the mode of union between all cup plates within a species is similar.

3. Fixed-brachials, which in larval stages represent free arms, are united with each other and adjacent plates by zygosynostosal unions.

4. Arm-bearing facets commonly have the most well-developed articulations of any plates, and they may occur on the most distal single fixed-brachials, two distal fixed-brachials that form a compound arm facet, or on the radials. Direction of greatest movement is largely determined by which type of union supports the free arms. Lateral movement is most prevalent in forms with large compound facets, and probably this direction of movement also occurred in forms in which the arms arise from a single plate. Movement of the arms in species with no fixed-brachials is greatest in a dorsoventral direction.

5. Articulating surfaces between biserial arm plates are smooth and nearly flat, indicating that in most forms little or no movement occurred between these plates; however, by development of numerous biserial plates some movement of the arm as a whole was possible. Thus, although some mobility of the arms is indicated, little was possible between two adjacent brachials, except possibly the arm-bearing facets and first arm plates. Supplementary structures that formed on the articular surfaces of brachials (e.g., radial striations, irregular vermiculations, grooves, etc.) resulted in greater rigidity between the plates.

6. In forms having free arms supported directly by the radials, the unions between uniserial proximal portions of the arms consist of fossae and crenulated marginal rims. This structure of the articular surfaces indicates that much greater flexibility between these ossicles was provided than between biserial brachials. Two or three fossae may be present, depending on which species is observed, and the number is constant within a species (except on distal surfaces of axillary plates). Commonly the depressions and crenellae become progressively less distinct on more distal brachials. Upward, the arms become biserial and distal brachials, as in other camerate species, are joined by nonflexible synostosal or zygosynostosal unions.

7. Articular surfaces observed on arm ossicles that support pinnules are extremely small, but observed structures indicate that a well-developed antagonistic system was present, which provided considerable relative mobility for the pinnules. Depending on species, these facets may consist of two fossae separated by a

raised area, or by three ligamentary depressions. Invariably, on surfaces with the latter type of articulation, the two outer fossae are smaller than the single, larger, inner one and their boundaries are less distinct. Thus, it seems that the primary function of the biserial nearly immovable brachials was to support the pinnules, which were flexible, at least in their proximal portions. Therefore, the pinnules functioned as the main food-gathering structures, as well as probably for support of certain reproductive organs.

8. Although not clearly seen, the unions between pinnulars of specimens studied seem to be united by zygosynostosal articulations. Therefore, just as the most proximal arm plates are the most flexible part of the arms, the corresponding surface of the pinnules also possesses structures that permit considerable movement.

9. Development of modified flattened, nonarticulating, nonpinnulate distal arm extremities is judged to be directly related to attempt by the organisms to keep waste matter from fouling the lower ambulacral areas. This specialized feature is undoubtedly associated with development of long anal tubes in forms in which the tegmen is completely surrounded by arms.

10. Articulations between apposed surfaces of plates forming the tubular appendages of *Gilbertsocrinus tuberosus* indicate that some limited amount of movement occurred in all directions. These unions are similar to syzygies present between brachials, rather than to interlocking symplexies, which are immovable and associated with stem ossicles.

11. Mode of union between all plates of camerate crinoids here studied is judged to be ligamentary; however, some tissues probably had limited contractile power, especially those that were lodged in well-developed fossae.

INADUNATA

Three workers (MOORE, STRIMPLE, WANNER) have contributed much to the knowledge of structures between plates of post-Mississippian inadunate crinoids, but comparatively few observations have been published concerning geologically older forms (except studies by BATHER, 11). This lack of information is in large part because most inadunates have their plates firmly united and artificial disassociation of ossicles is almost impossible. Information known concerning mode of union between plates is based largely on study of crinoid fragments or species in

which dorsal cups have been dislocated from arms so that radial facets are exposed. In my study, articular surfaces on specimens representing five species were examined, but it was not possible to observe all types of joint faces on a single individual specimen.

Articular surfaces on cup plates (except distal face of radials) of Crawfordsville species are nearly flat and structureless. However, the surfaces between these plates in *Barycrinus hoveyi* are slightly concave. Near the margins of plates the sides of depressed areas slope uniformly directed outward. This type of surface suggests that the connective tissue was not lodged in a distinct fossa.

Greatest differentiation of joint faces in inadunates occurs between radials and primibrachs, and between brachial plates. Two easily distinguishable types of unions are developed and these, along with other characters of the crown have been used as the basis for dividing dicyclic inadunates into two suborders. For convenience, these articulations may be designated as the cyathocrinoid and dendrocrinoid types of facets.

Crinoids assigned to the Cyathocrinoidea are characterized by having almost flat brachial faces. The radial facets are narrow, horseshoe-shaped or subrounded, and do not extend completely across the radial plate. Commonly brachials have slightly concave distal surfaces and gently convex proximal ones, which results in a nearly indistinguishable "ball-and-socket" type of union.

Typically, as shown in Figure 21, *1c,d,2d,3c,d*, a small rudimentary elevated ridge separates the ligament area into three distinct regions. This type of movable ligamentary union is termed a trifascial articulation, and was antecedent to true muscular unions. It allowed movement in all directions, but greatest mobility undoubtedly occurred dorsoventrally. Except for some well-developed ligamentary unions, as described above in section on Flexibilia, the trifascial type of surface afforded greatest mobility known to occur in crinoids with ligamentary articulations.

Commonly development of structures composing trifascial unions are most distinct on radial facets and proximal brachials. This distribution indicates that major movement of the arms occurred in this part of the crown. However, apparent absence of similar structures between more distal brachials may result because they are small and more easily destroyed.

Details of the structure and shape of the elevated ridge that separates the ligament fields vary considerably on specimens of the same genus, but the general three-fossae patterns of the facets normally remain distinct. On disassociated plates of *Pellecrinus hex-*

adactylus (Fig. 21,3) the elevated ridges were either nearly indistinguishable or well developed. Some facets were observed in which the ridge was very low and discontinuous across the facet. On radial facets of *Cyathocrinites multibrachiatus* the elevated ridges

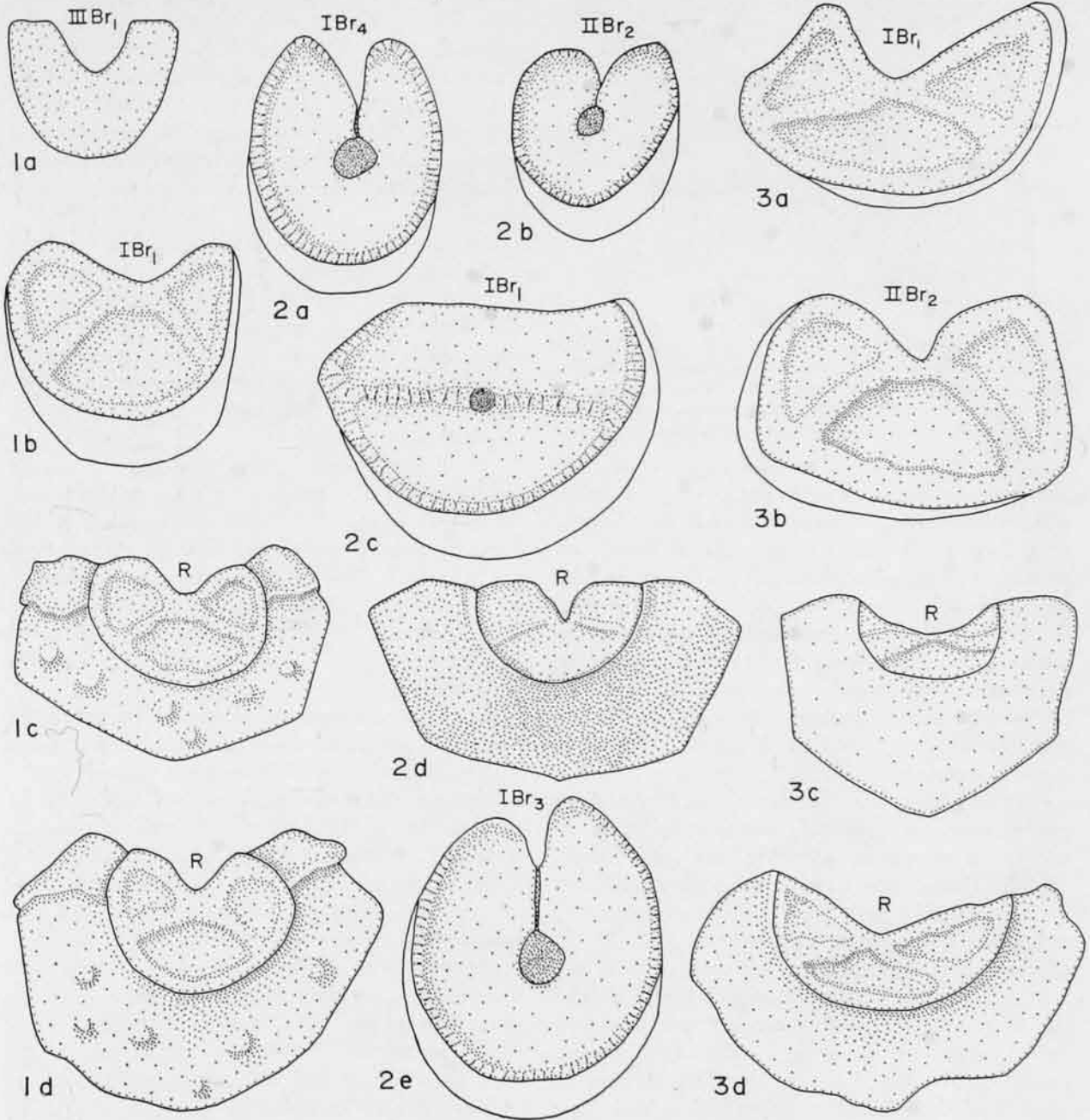


FIGURE 21. Articular surfaces on selected ossicles of several cyathocrinoid inadunates characterized by subcircular (or horseshoe-shaped) radial facets that lack well-defined transverse ridges and supplementary ligamentary structures (nerve canal commonly separated from ambulacral groove); all figures, X5, and all from different specimens.—1. *Cyathocrinites multibrachiatus*.—2. *Barycrinus hoveyi*.—3. *Pellecrinus hexadactylus*. [EXPLANATION: Plate designation same as in Fig. 10; all articulations occur on distal portion of plates.]

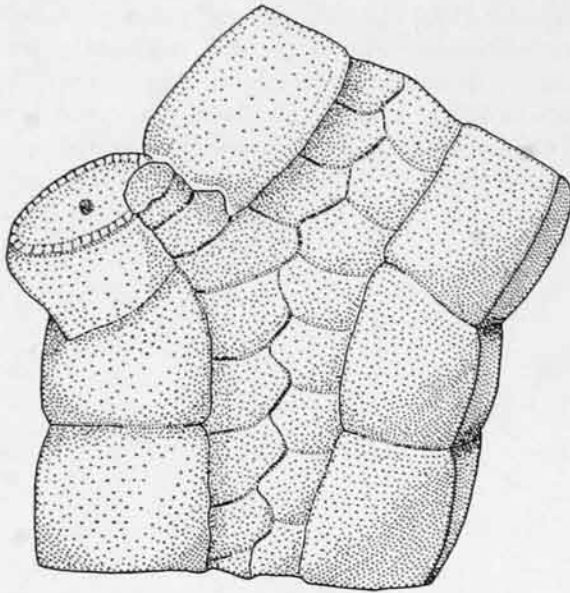


FIGURE 22. Camera lucida drawing of ventral surface of brachials (II Brr₂₋₄) on *Barycrinus hoveyi* showing arrangement of cover plates over ambulacral groove, approx. X10. [Note single row of plates covering ambulacral groove of armlet apposed to double row of plates over ambulacral groove of arm plates.]

and fossae are distinct and the degree of development is less variable than on joint faces of *P. hexadactylus* (Fig. 21, *lc,d*). Nearly similar trifascial unions are present on proximal brachials in both *P. hexadactylus* and *C. multibrachiatus*, but gradually the structures become less pronounced and at about the tertibrachs the articular surfaces appear to become smooth and structureless. This trend was observed on more than five well-preserved specimens of each species and probably was not caused by differential destruction of the structures.

Brachial joint faces of *Barycrinus hoveyi* differ greatly from the previously mentioned Crawfordsville inadunate species. Several radial facets were successfully disarticulated from arm plates and in all cases the elevated ridge is indistinct and does not extend completely across the articular surface (Fig. 21, *2d*). Brachials have a single large, but shallow, fossa that is nearly completely surrounded by a low crenulated rim (Fig. 22, *2a,b,c*). On one ossicle a straight narrow crenulated ridge separates the ligament field into two nearly equal areas, but corresponding surfaces in other rays of the same specimen and several other specimens examined, have a single fossa. This suggests that the development of a ridge is abnormal in this species. Invariably a subcentral nerve canal, which is separated from the ventral groove, can be seen.

As shown in Figure 22, the armlets have a single fossa and rimmed peripheral edge, as described for the brachials.

Trifascial articulations are not restricted to cyathocrinoid inadunates, but are also common between radials and proximal brachials of camerates in which the free arms are supported directly by the radials (Fig. 17, *4,6,7*; 19, *7,9*). Also, bifascial unions, as described above on an ossicle of *Barycrinus hoveyi*, were observed between brachials of the camerate *Platycrinites hemisphericus* (Fig. 19, *4*). SPRINGER (133, p. 138) stated that the radial facets of some crinoids assigned to the post-Paleozoic subclass Articulata (e.g., *Guettardicrinus* and *Hyocrinus*) possess trifascial unions.

An unusually well-preserved specimen of *Barycrinus hoveyi* provided information on arrangement of covering plates over the ambulacral grooves (Fig. 22). These plates are only rarely preserved in Paleozoic crinoids because they are thin and rather fragile. Covering the ventral surface of the brachials, a double row of alternating thin plates extends the entire length of the arms.

The most proximal plate covering the armlet groove, which also serves as a covering plate over ambulacral groove of brachial, enlarges and is followed by a single row of plates for the entire length of the armlets. This structure is in sharp contrast to the arrangement of covering plates on most other known crinoids in which a double row of plates covers the grooves of brachials, as well as the pinnules (or armlets).

The most advanced type of union between crinoid plates consists of complete muscular articulations. These articulations provide complete movable articulations upon wide straight facets, and completely fill the distal face of radial plates and distal and proximal surfaces of brachials. Rarely, muscular unions are found developed on other plates, such as on basals of specialized forms assigned to the calceocrinids, and possibly tegminal spines on advanced upper Paleozoic inadunates. The different structures developed on these surfaces are much more numerous and complicated than on any plates heretofore described. Generally the unions on Paleozoic crinoid ossicles are even more complicated than corresponding surfaces of Mesozoic and Cenozoic crinoids.

Typically, in Paleozoic crinoids a rather small dorsal (outer) ligament fossa is separated from a much larger inner area by a prominent, generally sharp-crested denticulate ridge that extends completely

across the joint face. The inner articular area consists of two subtriangular muscle areas and two smaller interarticular ligament fossae. On either side of the transverse ridge supplementary structures commonly can be observed consisting of small ridges, furrows, and pits. These structures have been clearly illustrated and defined by MOORE (103) and MOORE & PLUMMER (112) and are not redefined here because no significant additional information could be added from the few Crawfordsville specimens having muscular articulations that were available for my study.

Only specimens of a single Crawfordsville dicyclic inadunate (*Abrotocrinus unicus*) having muscular articulations was suitable for study of modes of union between plates. In addition, several dorsal cups of *Synbathocrinus swallowi*, a monocyclic form, had well-preserved radial facets.

The radial facets of *Abrotocrinus unicus* have a very narrow and straight nondenticulate transverse ridge that extends completely across the joint face, separating a rather long dorsal ligament area from the larger inner one (Fig. 23,2a). The outer portion

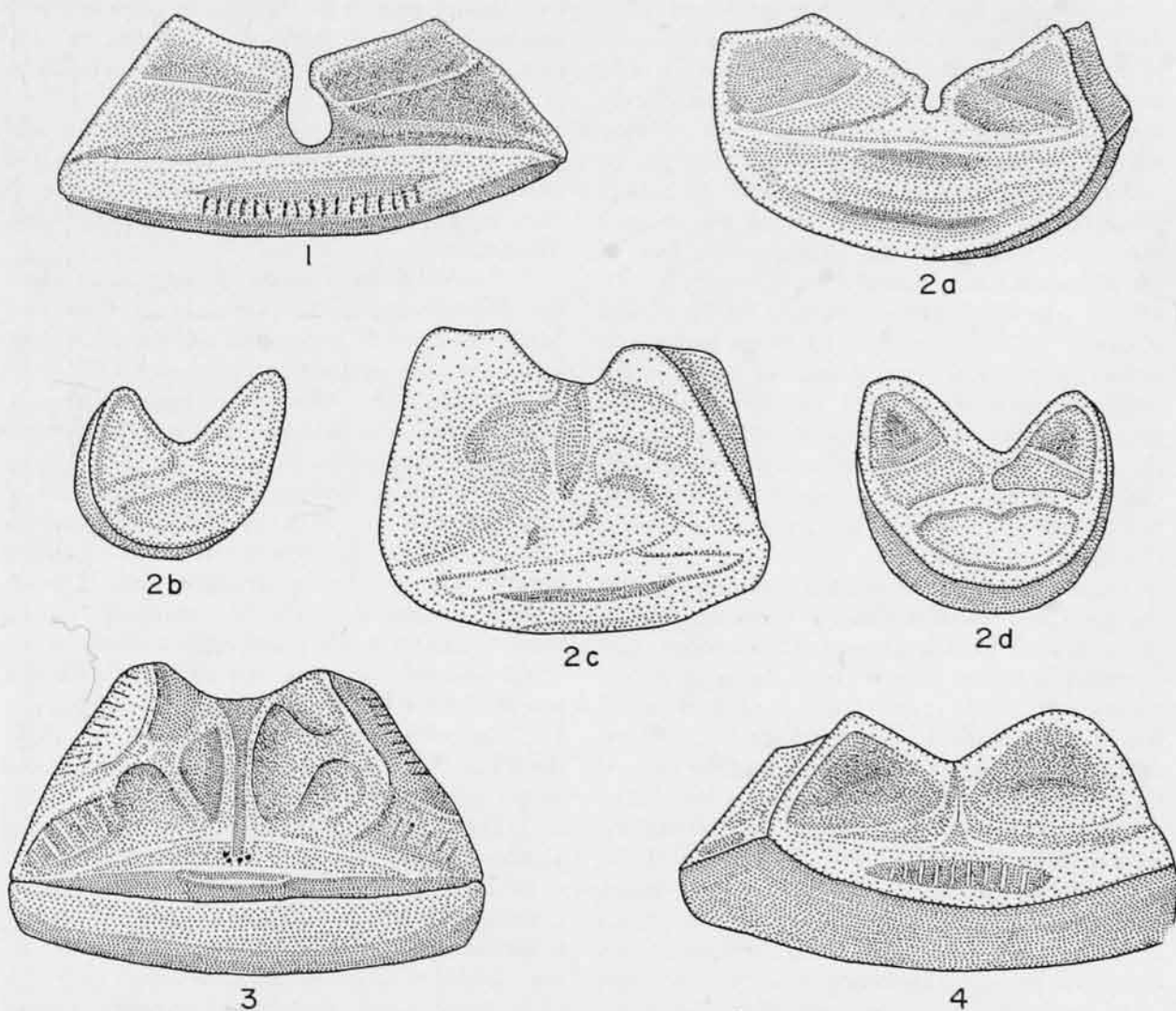


FIGURE 23. Advanced types of articular surfaces on selected inadunate crinoid ossicles.—1. *Erisocrinus obliquus* WANNER, Permian of Timor; radial facet, X6.—2. *Abrotocrinus unicus* (HALL), from Crawfordsville, Indiana; 2a, facet of C radial, X5; 2b, distal surface of IIIBr₂, judged to indicate ligamentary articulation, X5; 2c, ventral surface of IBr₁ (=IAX), showing complicated development of muscle fields, X5; 2d, distal surface of IIBr₃, X5.—3. Radial facet of *Graphiocrinus timoricus* WANNER, Permian of Timor, showing highly developed muscle fields in ventral portion of surface, X9.—4. Facet of C radial of *Synbathocrinus swallowi* HALL, from Crawfordsville, Indiana, showing inclined surface on left side for attachment of first anal plate, X8.

of the facet consists of a small ligament fossa adjoining the transverse ridge and a much wider fossa near the outer border of the face. Between these depressions a rounded elevated area is developed. On the inner side of the transverse ridge a central subtriangular platform-like area separates the two large muscle fields.

All primibrachs and secundibrachs, except axillary plates have a nearly similar structure, but the outer ligament area has only a single large dorsal fossa and a short intermuscular ridge that separates the two muscular fossae. Typically, the transverse ridge becomes broader and slightly arcuate inward (Fig. 23,2*d*). Beginning at about the tertibrachs the mode of union between plates becomes similar to trifascial unions and this type of structure continues distally until plates become so small that details of their articular surfaces are impossible to see (Fig. 23,2*b*).

Of particular interest is the nature of the axillary plates (Fig. 23,2*c*). Instead of having the articular surfaces restricted to the distal and proximal faces of the plates, the entire ventral (inner) surface has developed relatively complex structures for attachment of connective tissue. As far as I know, presence of articular surfaces on ventral faces of axillaries has not been previously reported, and it suggests that major development of muscular articulations was in the most proximal portions of the arms and between major bifurcations. However, considerable additional work must be done before the true relationships of these facets are known.

On all surfaces examined the boundary between the distal and ventral surfaces of the plates is indistinct. Inward from the transverse ridge (or more correctly, in a distal direction from the ridge, as now we are speaking of the ventral surface of the plate and not a distal or proximal joint face) the surface slopes uniformly. In the most distal portion of the axillary, two lobe-shaped fossae extend toward the lateral margin of the plate. Separating these areas and extending somewhat below them is a central, intermuscular furrow that is rather deep and broad. Around the furrow is an elevated region, which slopes gradually downward toward the muscle lobes. Below this portion of the articular face a single large, subtriangular low depression extends from near the outer margin of the plate, next to the transverse ridge, toward the intermuscular furrow. Similar structures were observed on 10 primaxils and secundaxils of *Abrotocrinus unicus* and on three primaxils of *Scytalocrinus robustus*.

Arm plates connected by muscular articulations also occur in some monocyclic inadunates (e.g., *Synbathocrinus*, Fig. 23,4) and are the most common type of union between radials and brachials in all post-Paleozoic crinoids. As far as now known, only inadunate and articulate species had well-developed muscular articulations. The most advanced type of union in other groups of crinoids was the trifascial ligamentary articulation.

GENERAL REMARKS

The above study of articular surfaces was necessarily almost entirely descriptive and important conclusions have already been cited; however, an additional remark or two of a general nature should be made.

The most advanced types of unions between crinoid plates occur between radial and brachial plates, and these may be divided into four main types; each more or less characteristic of major groups of crinoids. These include:

1. Brachial plates of almost all camerates in which fixed-brachials make up a portion of the dorsal cup (e.g., actinocrinitids, batocrinids, etc.) united by close, immovable articular surfaces with nearly flat structureless joint faces. This type of union is also the most common type on apposed surfaces of inadunate and camerate cup plates.

2. Articulations between radials and brachials of most species assigned to the Flexibilia consist of well-developed paired ligament fossae that are nearly completely surrounded by crenulated rims. Distinct transverse ridges are absent and commonly supplementary structures that added rigidity are developed in the ligament fossae. Similar appearing structures also are known to occur in other groups of crinoids (e.g., the camerate genus *Scyphocrinites*). Invariably the dorsal cup plates are also united by articulations admitting much mobility between plates.

3. Dicyclic inadunates assigned to the suborder Cyathocrinoidea, as well as several families referred to the Dendrocrinoidea (e.g., poteriocrinitids, dendrocrinids, botryocrinids), and camerates in which the free arms are borne by radials (e.g., *Platycrinites*) having rounded radial facets that are less than the width of the radial plates. These facets are mostly without a distinct transverse ridge and brachials are united by movable ligamentary unions only (trifascial, bifascial or unifascial articulations). Dorsal cup plates are united by smooth structureless faces of the zygonostiosial type.

4. Complete muscular articulation consisting of well-developed transverse ridge, inner muscular fossae, dorsal ligament fossa, and supplementary pits, ridges and furrows is found in the Paleozoic only among the Inadunata. Most forms assigned to the Dendrocrinoidea and several monocyclic inadunates have muscular unions, as in post-Paleozoic crinoids assigned to the Articulata. In this group the cup plates are commonly united by zygosynostosomal ligament unions and arm plates may have, in addition to muscular unions, synostosomal, synarthrial, or trifascial types of articular surfaces.

Many specialized groups of crinoids cannot be satisfactorily placed in any of the four groups and placement of some species must be arbitrary.

This study demonstrates that by careful application of various laboratory techniques the articular surfaces of most types of crinoids can be artificially disassociated. Important new information concerning basic morphology of Paleozoic crinoids can be gathered by additional studies of this sort.

SYSTEMATIC DESCRIPTIONS

INTRODUCTORY STATEMENT

Earlier descriptions of crinoids from Crawfordsville differ in completeness and in selection of characters judged important in differentiating species. Almost invariably species were founded on one, or at most only a few specimens, and no allowance was made for individual variation. Many have not been adequately described or figured and some have never been illustrated.

In general, the following procedure has been followed. (1) All species in which specimens were available for study are redescribed and illustrated; however, recently proposed ones (e.g., *Corythocrinus gracilis* KIRK, 61) and those adequately redescribed in a monographic study (such as SPRINGER's *Crinoidea Flexibilia*) are diagnosed but not described. (2) Species represented by specimens that I did not have opportunity to study are only diagnosed if the original reference is judged easily accessible, and descriptions in early (and commonly difficult to obtain) references are quoted directly from the original source. Many illustrations accompanying these early descriptions were so poorly made that photographic copies of them are nearly impossible to obtain, and thus no effort has been made to illustrate these.

Because most Crawfordsville species were originally placed in different genera than now considered correct, the citation of these forms follows recommendation 51 B of the *International Code of Zoological Nomenclature* (1961, p. 51), which states that both the original author of a species and the revisor who transferred it to another genus are cited. New combinations are also given in this form.

Publications that merely list bibliographical information (e.g., MILLER, 88; WELLER, 163; BASSLER & MOODEY, 9) and those citing only fossil occurrences (e.g., COLLETT, 31; BEACHLER, 16; CUMINGS, 33) are not included in synonymies of species unless they are nomenclaturally important because of new name combinations, name changes, etc.

Abbreviations used in this section for descriptions of crinoids are explained in Appendix A. (p. 126). The method employed for designating catalogued museum specimens was previously explained (p. 7). Nomenclatural citations and method of giving ranges of taxa above the species-group follow style adopted in the *Treatise on Invertebrate Paleontology*.

Typographical Methods Used to Classify Species

Different methods of citing species are used in order to differentiate valid from invalid species clearly, and forms that were originally described from the Crawfordsville beds from those first described from some other locality and later found at Crawfordsville. Thus:

1. A name in bold-face type not enclosed in brackets designates a valid species that was originally described from the Crawfordsville beds, as in the example, **Halysiocrinus bradleyi** (MEEK & WORTHEN, 1869), MOORE, 1962.

2. A name in light-face type not enclosed in brackets indicates that the valid species was first described from some other locality but later was found at Crawfordsville, as in the example, *Synbathocrinus swallovi* HALL, 1858.

3. Bold-face type with the citation enclosed in brackets is used for species originally described from Crawfordsville but now the species is rejected as a component of the Crawfordsville fauna, as in the example, [**Poteriocrinites nodobrachiatus** (HALL, 1861) BASSLER, 1938].

4. Light-face type with the citation enclosed in brackets is used for species first described from outside the Crawfordsville area and later erroneously reported from Crawfordsville, as in the example, [*Barycrinus bullatus* HALL, 1858].

A checklist of names applied to the Crawfordsville crinoids (Appendix B) is provided so that the valid species and synonyms can be rapidly checked.

INADUNATE CRINOIDS

As mentioned earlier, the inadunates are the most common group of Crawfordsville crinoids in numbers of species; however, individual specimens of the camerate forms were most common in the material available for study. The disparid inadunates are represented by only single known species of three genera, and the 16 cladid genera are assigned to 9 families and to a group in which the family allocation is not yet resolved. A total of 38 inadunate species have been described from the Crawfordsville beds.

Subclass INADUNATA Wachsmuth & Springer, 1897

Order DISPARIDA Moore & Laudon, 1943

[Ord.-Perm.]

Family ALLAGECRINIDAE Carpenter & Ethridge, 1881

[Dev.-Perm.]

Subfamily CATILLOCRININAE

Wachsmuth & Springer, 1886

[*nom. transl.* Moore, 1940] [Dev.-Perm.]

Genus EUCATILLOCRINUS Springer, 1923

[*Miss.* (Keokuk), Ind.]

Eucatillocrinus is represented in Crawfordsville beds by a single species, *Eucatillocrinus bradleyi* (MEEK & WORTHEN), known only from rocks of Keokuk age at this locality. It most nearly resembles *Catillocrinus* SHUMARD (1866), which differs in having 3 to 5 BB and a raised process on the left shoulder of the C-radial that supports a large anal plate; this plate characteristically interlocks with a massive anal tube that extends to or beyond the tips of the arms. Differences between these closely related genera are shown diagrammatically in Figure 24, 1*a*, 2*b*.

Eucatillocrinus bradleyi (MEEK & WORTHEN, 1868) SPRINGER, 1923

Plate 1, fig. 1, 2; text-fig. 24, 1*a*, *b*

Catillocrinus bradleyi MEEK & WORTHEN, 1868b, p. 343; 1873, p. 504, pl. 14, fig. 10*a*, *b*.

Eucatillocrinus bradleyi SPRINGER, 1923, p. 19, 27, pl. 3, fig. 14-17.

Diagnosis. Dorsal cup relatively high; summit of C radial (AR) even, supporting anal X on left and single arm at right; arms slender, very long. These same characters also distinguish the monotypic genus.

Description. Dorsal cup medium-sized, truncate cone-shaped, plates smooth or finely granulose, 3 BB, unequal, mostly concealed by stem, about a third height of cup, smallest plate in CD interray, sutures obscure; A and D radials moderately large compared to other forms in subfamily, C radial summit even, with no raised area at outer edge and no interlocking anal plate, A radial commonly slightly higher than other plates of R circlet; anal X resting directly on R at same level as arm bases; anal tube very long, rising above level of arms; arms commonly 40 to 46, rarely more, slender, Brr 2 to 3 times as long as wide; stem expanded near dorsal cup, tapering to fine point distally, cirri present only in extreme distal portion.

Remarks. *Eucatillocrinus bradleyi* most nearly resembles *Catillocrinus wachsmuthi* (MEEK & WORTHEN, 1866), from the upper Burlington Limestone of Iowa, especially if the nature of the C radial cannot be determined; however, *C. wachsmuthi* has a relatively shorter cup, with BB only slightly and unevenly exposed, and 24 to 39 arms that are proportionally thicker. *C. shumardi* SPRINGER (1923), from the Indian Creek beds, has a much smaller, less conical cup with BB barely visible in side view and 20 to 25 rather stout arms.

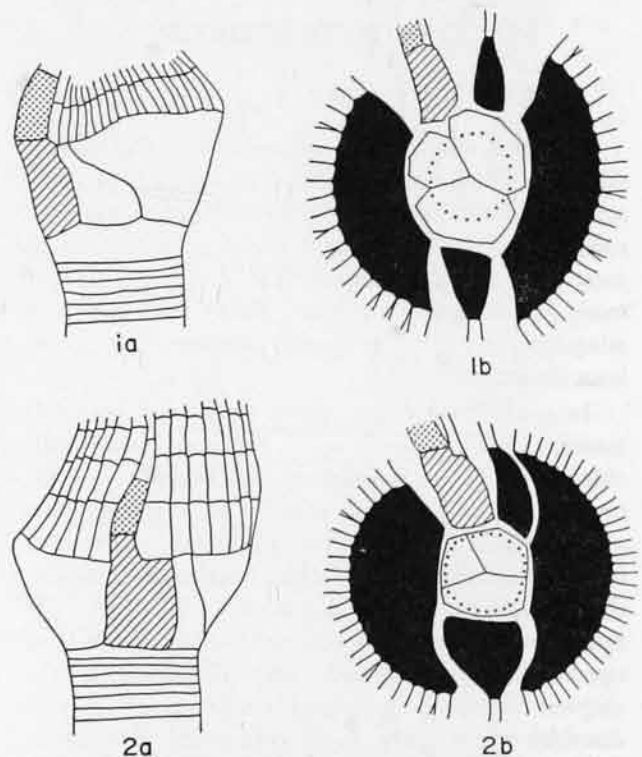


FIGURE 24. Diagrammatic representation showing relationship of plates in *Eucatillocrinus bradleyi* (1*a*, *b*) and *Catillocrinus wachsmuthi* (2*a*, *b*). Note especially different structure of plates supporting anal sac. 1*a* and 2*a* approximately X2.5. [EXPLANATION: Aniradial diagonally ruled; first plate of anal sac, designated anal X, stippled; radials in fig. 1*b*, 2*b*, black.]

Type. MEEK & WORTHEN's holotype is ISM (IGS) no. 2400. Presumably, SPRINGER's hypotypes are in the Springer Collection at U.S. National Museum.

Occurrence. Known only from Borden rocks at Crawfordsville. It was seemingly rare, as SPRINGER reported that he found only 6 specimens of it in his extensive Crawfordsville collection.

Material. In addition to the holotype, only two specimens (UCWM nos. 51827A,B) were available for study.

Dimensions. Measurements of *Eucatillocrinus bradleyi* are shown on Table 4.

TABLE 4. Measurements of *Eucatillocrinus bradleyi* in mm.

Measurements	Specimens		
	ISM (IGS) 2400	UCWM 51827A	UCWM 51827B
Dorsal cup height	4.9	7.0	5.9
Dorsal cup width	5.0	3.6	8.0
B cirlet height	1.8	1.9	1.8
A radial height	3.4		4.5
C radial height		3.9	3.4
D radial height		4.8	4.1
Stem diameter	4.3	4.9	4.7

Family CALCEOCRINIDAE Meek & Worthen, 1869

[M.Ord.-Miss.]

An important recent study by MOORE (106) completely discusses morphology and evolution of this group of highly specialized crinoids, as well as problems concerning incorrectly applied taxonomy. Terminology employed in study of calceocrinids varies markedly from other crinoids, and thus the above-mentioned study should be consulted for special terms used to describe the single known Crawfordsville species. The numerous excellent illustrations used by MOORE provide easy understanding of rather complicated terminology used.

Genus HALYSIOCRINUS Ulrich, 1886

[M.Dev., Iowa-Ind.; L.Miss., Iowa-Ind.-Ky.-Tenn.]

Halysiocrinus can be distinguished from all other calceocrinoids by the presence of inferradials of the B and C rays in contact with one another immediately above the stem impression (Fig. 25,2). The dorsal cup of the Silurian to Devonian genus, *Deltacrinus* ULRICH, 1886, closely resembles *Halysiocrinus*, but it has an angular margin on the median B directed toward the stem, rather than an arcuate one. The arm structure, however, is very different in the two genera. The former has an unbranched E ray and poorly-defined main axils and few axil arms that lack clear differentiation of alpha-, beta-, and gamma-ramules. *Halysiocrinus*, which somewhat resembles the Silurian genus *Chirocrinus* ANGELIN, 1878, in arm structure, has large well-developed main axils and arm axils, and isotomously or heterotomously branching arms in the E ray.

Only a single described species (*Halysiocrinus bradleyi*) has been reported from Crawfordsville, and as far as known, it is represented in the various collections only by the holotype. Previously, it was assigned with question

to *Halysiocrinus*; however, structure of the cup is without doubt similar to other forms of the genus. The arm structure differs somewhat from most other forms, however, in not bearing large beta-ramules.

Halysiocrinus bradleyi (MEEK & WORTHEN, 1869)

MOORE, 1962

Text-fig. 25, 1a,b

Calceocrinus? bradleyi MEEK & WORTHEN, 1869a, p. 73; 1873, p. 502, pl. 14, fig. 9.

Halysiocrinus? bradleyi BATHER, 1893, p. 67.

Halysiocrinus bradleyi MOORE, 1962a, p. 33, text-fig. 71.

Diagnosis. Crown tall and slender, composed of coarsely granular plates; E ray branching once isotomously on IBr₅; alpha- and beta-ramules borne on IIBr₃ and IIIBr₄, respectively, beta-ramule not conspicuously large, gamma-brachs (IVBrr) unbranched; nonaxillary Brr elongate, longer than wide, round; axillaries enlarged, rather inflated.

Description. Crown long, with very slender axil-arms that bifurcate twice, surface of plates coarsely granular. E radial divided; inferradial triangular, with long sloping sides, more than twice as wide as high; superradial smaller than inferradial, subtriangular, slightly more than half as long as wide. Median-arm (E ray) bifurcating isotomously once on IBr₅, IIBrr much smaller than more proximal Brr, tapering uniformly toward distal tips of arms. Main-axil (=IBrr) of D ray consisting of small nonaxillary IBr and 3 distant axillary IBrr (possibly 2 additional ones bearing a quartaxil-arm and omega-ramule are present adanally); other rays unknown. Axil-arms of D ray very long and slender; Brr quadrangular, longer than wide, slightly projecting at distal end; Axx more protuberant than nonaxillary Brr; IIBr₃ and IIIBr₄ in each series bearing an alpha- and beta-ramule, respectively; IVBrr simple, undivided, resembling adjacent ramules in size and shape. Stem long, relatively thick.

Remarks. The holotype (and only known specimen) of this species is preserved on a slab of rock, and thus only some of its characters can be defined. However, those observable indicate that the specimen represents a well-characterized species that differs significantly from other known forms.

Halysiocrinus bradleyi can be readily distinguished from other species assigned to the genus by the nature of bifurcation of the median-arm, shape and bifurcations of the axil-arms, and by the rounded appearance of the Brr (except slightly inflated Axx). The structure of the axil-arms of the A and D rays most closely resembles *H. dactylus* (HALL) from the Burlington Limestone, although this species has isotomous branching on the IBr₅ and higher isotomous or heterotomous branching in the E ray. Also the axil-arms are much shorter and more stout (Fig. 25,3). *H. nodosus* (HALL), from the

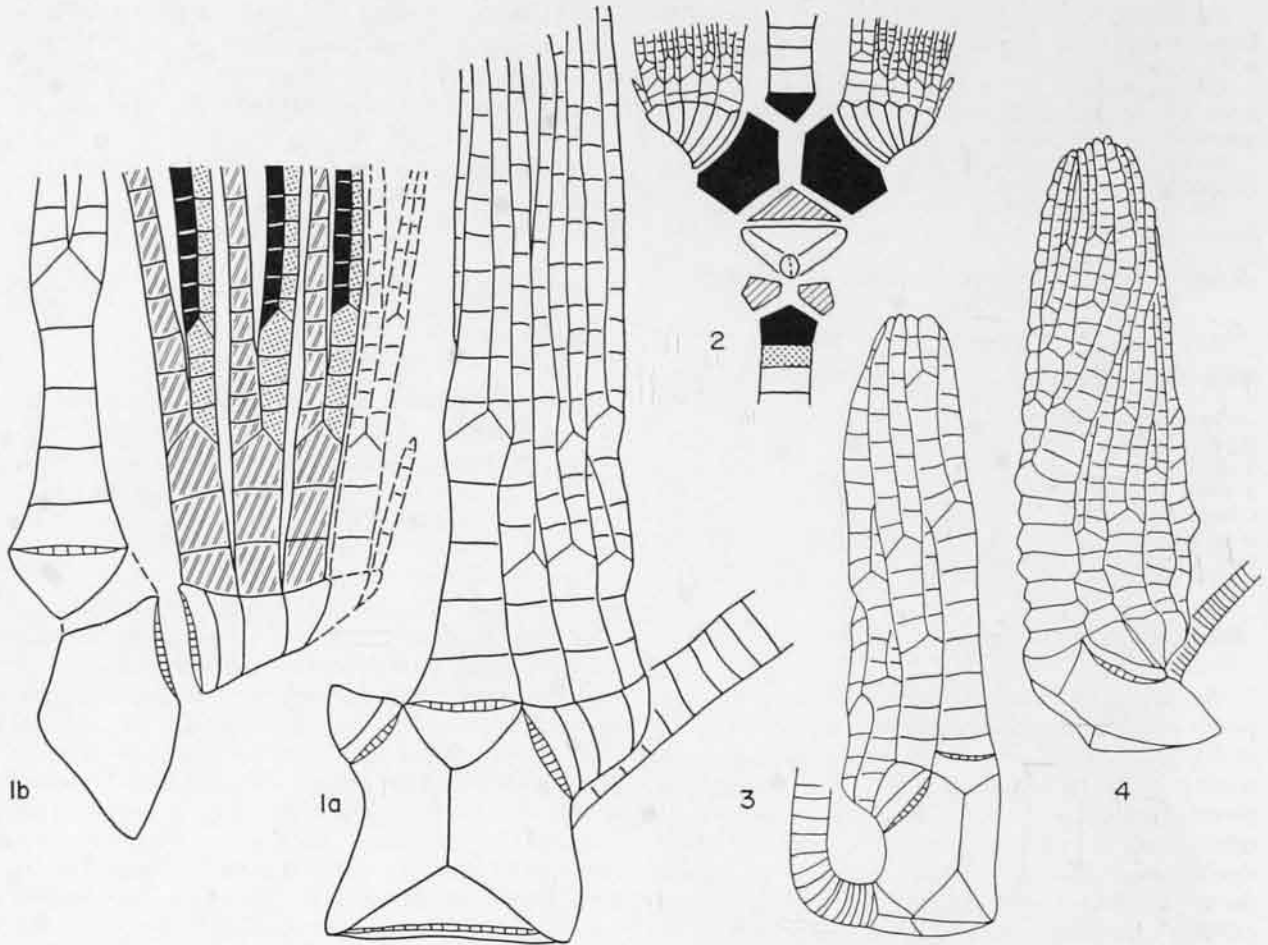


FIGURE 25. 1. *Halysiocrinus bradleyi*, approx. X1.5; 1a, camera lucida drawing of holotype; 1b, main-axil and axil-arm structures of same specimen spread to show structure of the arms and inferred quartaxil-arm and omega-ramule (after Moore, 1962b). [EXPLANATION: Alphabrachs and ramule, double oblique rule pattern; betabrachs and ramule, stippled; gammabrachs and ramule, black.]—2. Plate diagram of *Halysiocrinus* showing arrangement and shape of plates (107). [EXPLANATION: Radials, black; inferradials, diagonally ruled; anal X, stippled.]—3, 4. Line drawings of *H. dactylus* and *H. nodosus*, respectively, showing different modes of branching of median and axil-arms, X1.5 (139).

Indian Creek crinoid beds, differs from the Crawfordsville species in having isotomous branching on IBr_7 and heterotomous branches (at least 4) above on the E ray, 3 or more branches on axil-arms, and large nodes on most Brr , particularly on those of median-arm (Fig. 25,4).

Type. The holotype and only known specimen of this species is ISM no. 1809, now in the Illinois Geological Survey Collections.

Occurrence. The holotype of *Halysiocrinus bradleyi* was found in Borden rocks at Crawfordsville.

Dimensions. The following measurements were made on the holotype: maximum length of D radial, 12.4 mm.; width of same at center of plate, 5.4 mm.; width of R facet from main-axil on same plate, 5.5 mm.; maximum width of inferradial in E ray, 10.0 mm.; width of R facet of median-arm, 4.5 mm.; width of IBr_2 of median-arm, 2.8 mm.; width of $IIBr_2$ of secundaxil-arm, 2.0 mm.; preserved length of median-arm, 34.3 mm.; preserved length of axil-arms, 36.1 mm.; width of stem 3.4.

[*Halysiocrinus nodosus* (HALL, 1860) ULRICH, 1886]

Specimens of this species were cited by MOORE (1962a, Fig. 1, pl. 2, fig. 3 a-c) as occurring near Crawfordsville but this form actually came from the Indian Creek beds south of Crawfordsville.

[*Halysiocrinus tunicatus* (HALL, 1860) BATHER, 1893]

BASSLER & MOODEY (1943, p. 93, 501) reported that this species is known from the Crawfordsville crinoid beds, but this could not be confirmed in descriptions of the species or lists of fossils known from the locality.

Family SYNBATHOCRINIDAE S. A. Miller, 1889

[M.Sil.-M.Perm.]

Genus SYNBATHOCRINUS Phillips, 1836

[Dev.-Perm., N.Am.-Eu.(Gt. Brit.)-Timor]

Synbathocrinus, like other members assigned to the synbathocrinids, is relatively simple, nearly symmetrical and a rather stable genus that seemingly branched early from its ancestral form and changed little during its rather long range. Surprisingly, over 30 species have been assigned to this genus, but no doubt a revision of it would result in many forms becoming classed as synonyms. Most species are defined on very slight differences in size and shape of the dorsal cup, characters of the arms, and character of notch on left lateral side of AR that supports the anal X; however, as observed in the Crawfordsville material these features are quite variable (Fig. 26).

Synbathocrinus differs greatly from other Crawfordsville species and it is surprising that it has not been previously reported from these beds. Persons not trained in crinoid paleontology possibly might confuse this genus with *Eucatillocrinus*, but the single robust arms composed of rather large quadrangular Brr and the nature of the dorsal cup and R facets of *Synbathocrinus* easily distinguish the latter genus.

Synbathocrinus swallowi HALL, 1858

Plate 1, fig. 6; text-fig. 23,4; 26,1

Synbathocrinus swallowi HALL, 1858, p. 672, pl. 17, fig. 8, 9.

Synbathocrinus swallowi BEEDE, 1906, p. 1262, pl. 13, fig. 11, pl. 14, fig. 1 (invalid name change).

Diagnosis. Dorsal cup medium-sized to large, low cone-shaped, broad distally, truncated base relatively small; IBB low; Brr proportionally short.

Description. Crown elongate, commonly attaining a rather large size, base slightly depressed for reception of stem. BB barely visible in side view, sutures indistinct; RR quadrangular, wider than long, expanding rapidly upward, C and D radials slightly to deeply beveled on left and right distal extremities. Arms barely tapering distally, IBrr₁ slightly longer than succeeding ones; proximal Brr angular, becoming uniformly convex distally, quadrangular. Stem narrow.

Remarks. Crawfordsville specimens assigned to this species are typically larger than most other specimens known; however, because other features resemble *Synbathocrinus swallowi* and specimens varying greatly in size are known from this locality they are assigned to this species. Curiously, this form has not been reported previously from Crawfordsville, but judging from the amount of material available it was not a particularly rare form. *S. wachsmuthi* MEEK & WORTHEN (1869) closely resembles this species but can be distinguished rather easily by its distinctly angular Brr, which extend nearly the full length of the arms.

HALL's name *Synbathocrinus swallowi* was probably

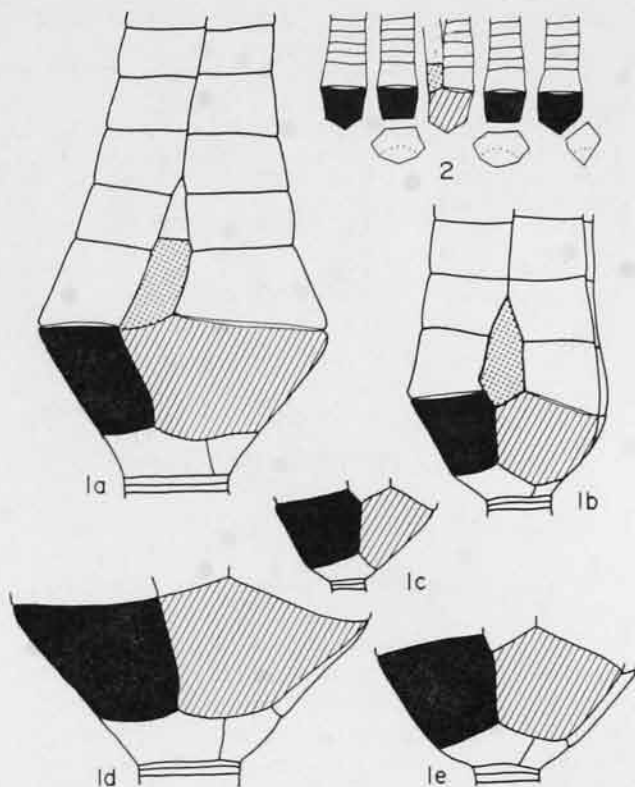


FIGURE 26. 1a-e. Camera lucida drawings of specimens of *Synbathocrinus swallowi* from Crawfordsville showing variation in size and shape of dorsal cup and notch supporting first anal plate (X2.5).—2. Plate diagram of *Synbathocrinus*. [EXPLANATION: radials, black; aniradial, oblique ruled; anal X, stippled.]

an error for *swallowi* (named for GEORGE CLINTON SWALLOW of the University of Missouri); however, direct proof of this cannot be obtained from his original description. Thus, the name must be retained as originally published and BEEDE's subsequent corrected name cannot be substituted.

Type. HALL's holotype, reported from the St. Louis Limestone near St. Louis, Missouri, could not be located. Because only specimens from Crawfordsville were available, no attempt to designate a neotype was made.

Occurrence. BASSLER & MOODEY (1943, p. 696) reported that this species is known from the St. Louis Limestone, near St. Louis, Missouri; Keokuk Limestone at Keokuk, Iowa, and Canton, Indiana; Warsaw Limestone at Boonville, Missouri, and Colesburg, "etc.," Kentucky; Spergen Limestone, Spergen Hill, Lanesville, "etc.," Indiana. To this list must now be added Borden rocks at Crawfordsville.

Material. Thirteen specimens of *Synbathocrinus swallowi* were available for study. Except for one specimen, all were loaned by the New York State Museum. The following catalogued specimens were measured: UCWM no. 8908; NYSM nos. 11481a, 11622-11627.

Dimensions. Measurements are shown on Table 5.

TABLE 5. Measurements of *Synbathocrinus swallowi* in mm.

Measurements	Specimens*							
	1	2	3	4	5	6	7	8
Dorsal cup height	3.8	6.0	7.0	7.0	3.2	4.1	3.0	2.4
Dorsal cup width	8.1	14.8	12.9	12.0	12.8	10.7	6.8	5.3
Basal circling height	1.4	2.9	2.5	2.5	1.9	1.8		0.9
Basal circling width	4.5	8.0	7.5	7.0	6.8	5.7		3.0
Radial circling height	3.4	5.9	4.8	4.8	4.1	4.0		2.1
Arm facet width	3.8	9.0	7.7	9.1	8.0	5.8	4.0	3.0
Stem diameter	2.9	4.7	4.6	4.3		3.1	2.2	2.3
Arm length	42.0	27.6						

* 1, UCWM 8908; 2-8, NYSM 11481, 11622-11627, respectively.

Order CLADIDA Moore & Laudon, 1943

Suborder CYATHOCRININA Bather, 1899

[Ord.-Perm.]

Family AMPHERISTOCRINIDAE Miller, 1889

[Sil.-Miss.]

Genus PARISOCHRINUS Wachsmuth & Springer, 1880

[Sil.-L. Carb., N. Am.-Eu.-USSR]

This genus is rather easily confused with *Cyathocrinites*, which is closely related, and with some species of *Poteriocrinites*. It resembles the former in having a similar-shaped theca, arm facets, arms, and anal tube, but it has 3 anals within the cup. *Poteriocrinites*, which also has 3 anal plates differs in having a long, thin-plated, corrugated anal tube, which commonly rises above its arms. Also the anal opening is below the distal portion of the tube, rather than at the summit, as on specimens of *Parisocrinus*.

Parisocrinus crawfordsvillensis (MILLER, 1882)

WACHSMUTH & SPRINGER, 1886

Plate 1, fig. 7, 8, 11; text-fig. 27

Cyathocrinus crawfordsvillensis MILLER, 1882, p. 79, pl. 3, fig. 1.

Parisocrinus? crawfordsvillensis WACHSMUTH & SPRINGER, 1886, p. 312.

Poteriocrinus subramosus MILLER & GURLEY, 1890, p. 49, pl. 10, fig. 1 (private publ.); p. 365, pl. 10, fig. 1.

Parisocrinus subramosus SPRINGER, 1900, p. 145, pl. 16, fig. 1-4; 1911, p. 157, pl. 4, fig. 18.

Poteriocrinites circumtextus MILLER & GURLEY, 1894, p. 31, pl. 2, fig. 29, 30; MILLER, 1897b, p. 751, fig. 1385; WELLER, 1900, p. 37, text-fig. 25, p. 41, fig. 29; SPRINGER, 1911, p. 157.

Diagnosis. Dorsal cup low, conical, plates smooth, sutures distinct; anal X and RA subequal, RT plate about half as large; anal tube long, pore-bearing, with large anal pyramid plates at summit covering anal opening; arms long.

Description. Theca obconical, dorsal cup expanding uniformly from base, plates rounded. IBB large, higher than wide; BB subequal in size, about as wide as long; RR about twice as wide as high, R facet more than half width of plate. Anal X supported below by truncated upper surface of CD basal and laterally in contact with

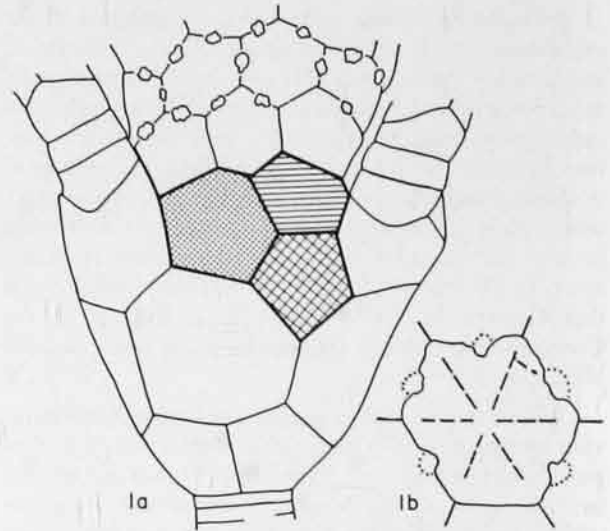


FIGURE 27. 1a. Camera lucida drawing of *Parisocrinus crawfordsvillensis* (holotype of *Poteriocrinus circumtextus*) showing arrangement of plates in CD interray and pore-bearing proximal plates of anal sac, X3.—1b. Enlarged distal anal sac plate showing location and irregular outline of pores, X8 (dashed lines indicate axes of radially arranged ridges). [EXPLANATION: anal X, stippled; radial, cross ruled; right tube plate, horizontally ruled.]

D radial and upper left portion of RA; anal X supporting 2 rather large, smooth, tube plates which may or may not be pore-bearing in their distal portions and right obliquely with RA supporting somewhat smaller RT. Anal tube covered with alternating series of hexagonal plates, commonly with conspicuous stellate ridges that are directed to angles of plates; anal tube pores invariably located on suture lines along sides of hexagonal plates. Arms long, slender, first bifurcating on IB_{R3-4} and numerous additional branches at irregular intervals.

Remarks. Remarkable preservation of several specimens of this species at Crawfordsville afforded SPRINGER opportunity to study details of the anal tube. The size, shape, and distribution of pores along the tube are variable, but without exception, when present, they are located along suture lines between angles of the plates. Thus, each opening is shared by two adjacent plates. As shown on Fig. 27 the pores begin on the upper surface of the plates next above anal X and RT. Commonly six pores are shared by each plate, but rarely one or more sides may be devoid of them. Figure 27, 1b shows a single tube plate in more detail and illustrates more clearly the subcircular oval appearance of the pores, which resulted in part from post-burial compression. Seemingly, the function of the anal tube was in part respiratory; however, the rather large anal opening at the top of the tube indicates that waste material was also extruded by this structure, as in camerates.

MILLER & GURLEY's *Poteriocrinus subramosus* and *P. circumtextus* are similar to this species, except in size

of the dorsal cup and length of the arms. The former was illustrated at somewhat smaller scale than was indicated, and thus comparisons of only illustrations of this form with those of *Parisocrinus subramosus* are misleading.

Type. The holotype of *Parisocrinus crawfordsvillensis* is USNM no. 41086. MILLER & GURLEY's holotypes of *Poteriocrinus subramosus* and *P. circumtextus* are UCWM nos. 6255 and 6447, respectively. SPRINGER's hypotype (1900, pl. 16, fig. 1) is USNM no. S-3796, and his specimen illustrated in 1911 (pl. 4, fig. 18) is USNM no. S-2331.

Occurrence. Specimens of this species were reported by SPRINGER to be rather common in both the Crawfordsville beds and those along Indian Creek.

Material. The following specimens were available for study: plaster casts of MILLER's holotype of *Parisocrinus crawfordsvillensis*, SPRINGER's hypotypes, and MILLER & GURLEY's holotypes, UCWM no. 8907, ISM 10172 (IDG no. E1425).

Dimensions. Measurements are shown on Table 6.

TABLE 6. Measurements of *Parisocrinus crawfordsvillensis* in mm.

Measurements	Specimens*					
	1	2	3	4	5	6
Dorsal cup height	9.0	10.2	12.3	12.1	9.9	9.9
Dorsal cup width	13.2		18.1	14.0	11.0	12.5
Basal plate height	5.0		6.1	6.1	5.0	5.1
Basal plate width	5.1		7.2	6.0	4.8	4.9
Radial plate height	3.5	3.2	4.8	4.8	3.6	4.0
Radial plate width	4.9	5.7			5.1	5.0
Arm facet width	3.4	3.1		3.5	3.0	3.7
Arm length	70.7					
Anal sac height	53.1		71.7		45.0	
Stem diameter		3.3	5.4	5.0	3.7	3.8

* 1-3, USNM 41086, S3796, S2331; 4-5, UCWM 6255, 6447; 6, ISM 10172.

Family BARYCRINIDAE Jaekel, 1918

[Miss.]

Genus BARYCRINUS Meek & Worthen, 1868

[L.Miss. (Burlington-Keokuk-Warsaw), N.Am.]

All previous workers have cited WACHSMUTH as author of this genus; however, it should be credited to MEEK & WORTHEN. These authors (78, p. 338) credited WACHSMUTH as the author, but indicated that he proposed the name only in an unpublished manuscript, which was made available to them during preparation of their article. Thus, according to the rules of nomenclature MEEK & WORTHEN were first to publish the name and must be considered as authors of the genus.

Examination of numerous specimens of *Barycrinus* found at Crawfordsville indicates that number and arrangement of the arms is constant in most species, although in specimens classed as belonging to *B. hoveyi* the number was found to vary from 10 to 16. Previously, specimens assigned to this species were defined by presence of 16 arms, and those with 12 arms were placed in MEEK & WORTHEN's *B. herculeus*. Since these forms have similar crowns and arm variations from 10 to 16

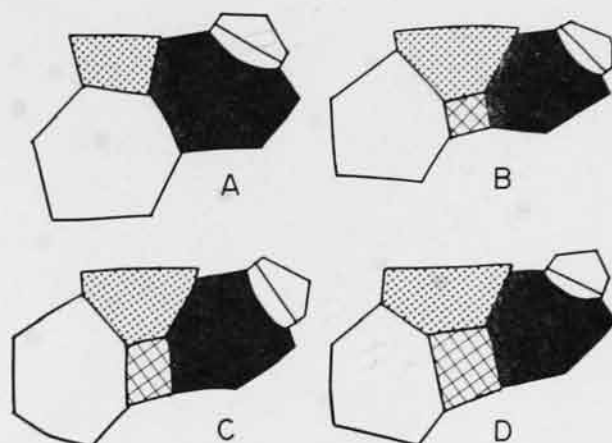


FIGURE 28. Diagrammatic representation of plates in CD interray of four specimens of *Barycrinus hoveyi* showing reduction in size and eventual elimination of radial from dorsal cup. [EXPLANATION: Anal X, stippled; radial, cross ruled; C radial, black.]

have been observed, not to mention different arrangement of bifurcations, in my opinion these specimens represent a single species.

The presence or absence of a RA, commonly used in definition of species belonging to various inadunate genera cannot be considered taxonomically important in forms of *Barycrinus*. Study of this plate in specimens of *B. hoveyi* indicates that its size differs considerably among individuals and that its absence is not a result of upward migration and eventual elimination from the cup, as in many inadunates (e.g., *Zeacrinites*, *Sundacrinus*). Figure 28 illustrates diagrammatically the relationship of the RA to adjacent plates of this species, and suggests that the most logical explanation for its absence is by resorption, rather than upward migration.

Barycrinus hoveyi and *B. herculeus* are here considered to represent a single species, for reasons cited above, and MILLER & GURLEY's *B. princeps* and *B. neglectus* are redescribed. The new species, *B. asteriscus*, is proposed for Crawfordsville specimens previously assigned to *B. angulatus* and *B. stellatus* which are entirely different from the Crawfordsville species.

Barycrinus asteriscus VAN SANT, n.sp.

Plate 1, fig. 3-5, 9, 13; text-fig. 29

Diagnosis. Dorsal cup low, medium-sized; large, flattened nodes on BB, appearing stellate in ventral view, angles rounded, commonly with distinct but small narrow groove in proximal median portion of each node; smaller nodes present on RR and some Brr; arms with pronounced zigzag appearance because of well-developed SAxx, armllets well-developed.

Description. Dorsal cup bowl-shaped, expanding moderately upward, truncated at base; plates smooth to

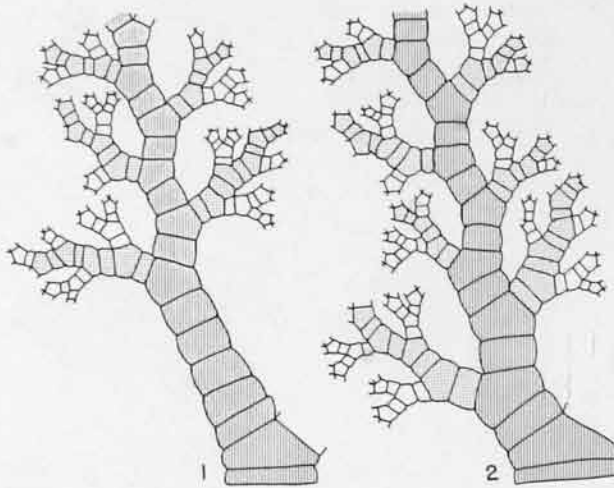


FIGURE 29. Nature of arm branching of *Barycrinus asteriscus* showing left bifurcation above primaxils of anterior ray (1) and normal type of branching in other rays (2); main arm, vertically ruled; armlets, stippled; ramules, unmarked, approx. X1.

slightly granulose. IBB small, truncated on plane with tumid portion of BB; BB about as wide as long, proximal edge appearing straight, with no distinct angle in middle portion of suture; large rounded nodes on middle half to two-thirds of plates; RR large, much wider than long, with well-developed median nodes, which diverge from near upper portion of plates to near base, appearing as single rounded, somewhat flattened protuberance or as 2 coalescing nodes, R facets slightly concave. Anal X rather large, wider than high, about in line with RR, pentangular; RA small, in normal position, quadrangular. Anal tube unknown. Arms 10, long, bifurcating once above IBr_2 , zigzag appearance resulting from well-developed $SAXx$ that bear alternating rather large armlets at intervals of 2 Brr , these in turn bearing ramules; IBr_1 extremely short, IBr_2 axillary, commonly with low, rounded median nodes that are subequal in size; higher Brr somewhat wedge-shaped, nodes commonly especially on $SAXx$. Stem round, moderately long.

Remarks. Numerous Crawfordsville specimens previously considered to belong to HALL's *Barycrinus stellatus* and MEEK & WORTHEN's *B. angulatus* are considered herein to represent the new species *B. asteriscus*. These forms superficially resemble *B. angulatus*, and are closely related to it; however, the latter differs in having a more robust dorsal cup, larger and thicker plates that are strongly convex. In addition, nodes on the BB are much larger, and have a wider, more distinct furrow. Also MEEK & WORTHEN's species lacks nodes on RR and Brr . *B. stellatus*, which probably is a synonym of *B. angulatus* differs from the latter only in having slightly thinner plates and smaller, less distinct nodes on the BB.

S. A. MILLER's *Barycrinus stellifer* differs from *B.*

asteriscus in having more pointed angles of basal nodes when viewed ventrally, lack of beveled appearing depressions between nodes, more restricted, and smaller nodes on RR.

Type. The holotype, selected herein, is YPM no. 6452.

Occurrence. This species is restricted to rocks of Borden age and has been found only in Montgomery County, Indiana. Specimens labelled *B. stellatus* from Indian Creek also probably belong to this new species. Judging from the amount of material available for study, this species was moderately abundant in the Crawfordsville beds.

Material. Fifteen specimens of *Barycrinus asteriscus* were available for study, of which eight were selected for measurements. These include the holotype, YPM nos. 6452B,C,D,E.; UCWM nos. 8898A,B; WC no. 64.

Dimensions. Measurements are shown on Table 7.

TABLE 7. Measurements of *Barycrinus asteriscus* in mm.

Measurements	Specimens							
	1	2	3	4	5	6	7	8
Dorsal cup height	10.4	12.6	13.2	12.0	9.7	12.0	10.8	
Dorsal cup width	13.5	19.6	21.0	12.2	14.6			
Basal plate height	6.0	7.6	8.4	9.0	6.7	8.0	5.7	7.0
Basal plate width	6.4	7.8	8.6	9.3	6.8	8.5	6.8	7.2
Radial plate height	3.4	5.8	5.0	4.0	3.0	4.7	2.5	5.2
Radial plate width	9.5	11.1	11.2	10.4	8.7	9.6	9.4	10.1
Arm length	41.1	54.4						
Stem diameter	5.0	6.5	6.1	5.2	4.8	4.4	4.6	

1-5, YPM 6452 A-E; 6-7, UCWM 8898 A, B; 8, WC 64.

[*Barycrinus bullatus* HALL, 1858]

BASSLER & MOODEY (1943, p. 92, 317) report that specimens of this species were reported from Crawfordsville, but published descriptions fail to confirm this.

Barycrinus hoveyi (HALL, 1861)

MEEK & WORTHEN, 1873

Plate 1, fig. 16; pl. 2, fig. 5, 7-9; text-fig. 21,2; 22, 28; 30

Cyathocrinus hoveyi HALL, 1861a, p. 293; 1872, pl. 5, fig. 11.
Barycrinus hoveyi MEEK & WORTHEN, 1873, p. 486, pl. 13, fig. 1.
Barycrinus hoveyi var. *herculeus* MEEK & WORTHEN, 1868b, p. 341; 1873, p. 485, pl. 13, fig. 2.
Barycrinus herculeus WACHSMUTH & SPRINGER, 1879 (1880), p. 102.
Cyathocrinus corrugatus TROOST, 1849, p. 419 (*nom. nudum*).
 Wood, 1909, p. 85.

Diagnosis. Crown extremely large to medium-sized; broad well-defined depressions between BB and RR; arms 10 to 16, location of bifurcations variable.

Description. Dorsal cup large, robust, bowl-shaped; surface distinctly granulose on well-preserved specimens; plates convex, curving abruptly inward at lateral and distal edges of BB and on proximal and lower lateral edges of RR, distal arcuate portion of IBB may or may not take part in interbasal depression. IBB large, angular at upper extremities, truncated at base; BB very large, nearly as wide as high; RR very large, much wider than

high, height varies considerably on same specimen; R facets slightly concave, half to two-thirds width of RR. Anal X large, in line with RR, quadrangular or pentagonal, depending on presence or absence of RA; RA commonly absent, if present small, quadrangular, in normal position. Anal tube low, not extending to tips of arms. Arms robust, long, smooth; 2 IBrr, Brr slightly wedge-shaped, tapering rather abruptly but uniformly in distal portions; bifurcations variable; armlets borne alternately at intervals of 2, large to medium-sized. Stem long, consisting of alternating larger and smaller plates.

Remarks. MEEK & WORTHEN originally proposed *Barycrinus herculeus* as a variety of HALL's *B. hoveyi*, and stated that their form was similar in all respects, except arrangement of arms. Examination of more than 25 specimens indicates that the number and location of arm bifurcations in this species is not fixed, but varies considerably (Fig. 30). As a result, dorsal cups identical

in appearance may be associated with 10 to 16 arms. Because no other character of taxonomic importance is known to differ significantly, the specimens previously assigned to the above-mentioned species are here considered to represent a single species. If the nature of bifurcations is thought to be a valid basis for separating species then several additional new forms would have to be proposed for variations observed.

Barycrinus hoveyi, as originally described by HALL, has the anterior division of the B and E rays bifurcating twice above the IAxx, and the posterior arms remain single. The C and D rays show a single bifurcation on the lateral side above the IAxx, and the arms remain single above the IAxx in the A ray. According to definition, *B. herculeus* is characterized by single arms above the IAxx in the A, C, and D rays, and a single bifurcation above the IAxx on the posterior side of the B and E rays. Thus, the first-mentioned species has 16 arms, and the

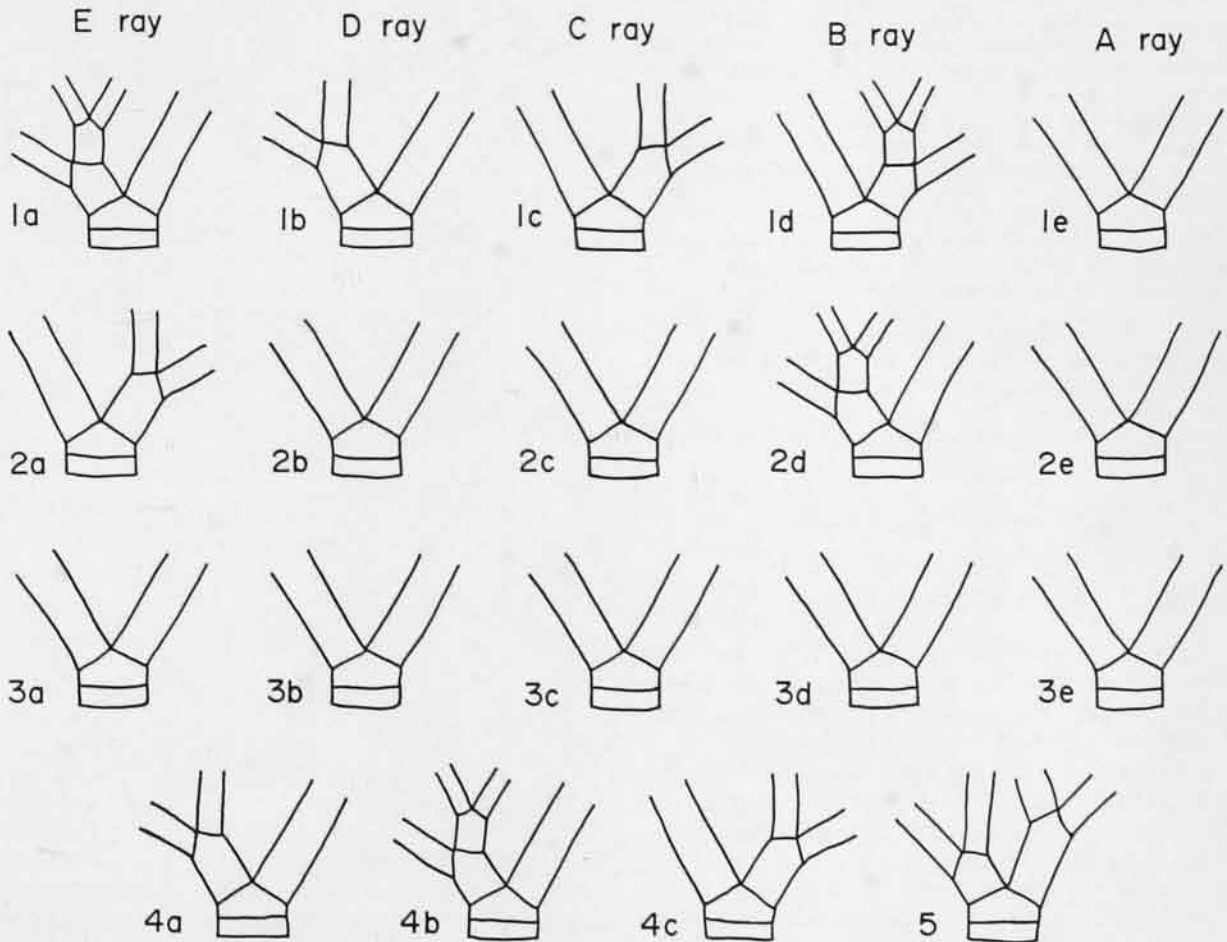


FIGURE 30. Patterns of arm branching in *Barycrinus hoveyi*.—1. Pattern according to original description of species.—2. Mode of branching described for *B. herculeus*.—3. Pattern observed on UCWM nos. 8932 A,B,C, ISM no. 1805.—4. Pattern observed on plaster cast of AMNH no. 7161/5.—5. Abnormal type of branching on UC no. 25024. (Orientation of rays shown in 4 and 5 unknown).

latter possesses 12. These are present on several specimens available for study, but most commonly the arms remain single above the IA_{xx}, resulting in 10-armed individuals. On some a bifurcation takes place on both divisions above the IA_{xx} and on others certain rays have bifurcations more characteristic of other rays. Figure 30 illustrates the observed variation of arm patterns in this species.

Barycrinus hoveyi can be distinguished easily from other specimens of this genus at Crawfordsville by its robust size, distinct interbasal and interradsial depressions, and 10 to 16 long tapering arms that bear stout ramules. Ten-armed specimens closely resemble MEEK & WORTHEN'S *B. spectabilis* from the Keokuk Limestone of Illinois in size and arrangement of arms; however, the latter possesses rather large nodes on the BB and deeply depressed areas at the angles of the cup plates. Also it has irregularly arranged nodes on the distal portion of the RR.

Type. HALL'S holotype is at the Illinois State Museum (Springfield, ISM No. 1617). Only a plaster cast of this specimen (UCWM No. 15816) was available for study. MEEK & WORTHEN'S holotype of *Barycrinus herculeus* is ISM No. 1805, which is also deposited at the museum in Springfield.

Occurrence. Specimens referable to this species have been unquestionably reported only from Crawfordsville and Indian Creek, Indiana. BASSLER & MOODEY stated that it was also reported from Keokuk, Iowa, but this was not confirmed in published descriptions of the species. TROOST'S specimen from the Ft. Payne Chert of Kentucky (USNM No. 69947) probably represents another species.

Material. In addition to the types mentioned above, the following specimens were available for study and used to obtain measurements: Plaster cast of AMNH no. 7161/5; UCWM nos. 8923A-G, 8931, 8904, 51280; YPM nos. 22751A,B, 6451A,B; IDG no. E1158; NYSM no. 11472; UC nos. 25024A,B; WC no. 20. Several other uncatalogued specimens were available but were not used for measurements.

Dimensions. Measurements of *Barycrinus hoveyi* are shown on Table 8.

Barycrinus? neglectus MILLER & GURLEY, 1896

Plate 1, fig. 10, 12

Barycrinus neglectus MILLER & GURLEY, 1896, p. 28, pl. 2, fig. 10-12.

Diagnosis. Theca obconical, small; deep longitudinal depressions between BB, small, rounded, deep pits at angles between BB and RR; R facets gaping, nearly three-fourths width of RR.

Description. Dorsal cup tapering uniformly outward to distal portion of RR, height nearly equal to greatest diameter of cup, surface granular. IBB longer than wide, forming more than a third of the length of cup; BB longer than wide, lateral edges curving inward abruptly to form portion of interbasal depressions; RR wider than long, proximal lower sloping edges curving inward abruptly, forming interradsial pits, median portion of proximal edge forming part of longitudinal interbasal depressions. Anal X in line with RR but larger

TABLE 8. Measurements of *Barycrinus hoveyi* in mm.

Measurements	Specimens																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Dorsal cup height	22.6	22.3	26.0	16.6	20.4	23.0	19.0	17.6	17.9	29.1	22.0	12.8	15.2	22.4	22.5	21.2	12.7	20.8	20.3	16.0	13.2	
Dorsal cup width	41.0	42.6	45.0	17.0	29.8	37.0	26.3	28.5	29.6	46.2	24.2	24.2	34.0	31.6	34.1	34.8	34.8	34.8	34.8	34.8	22.1	22.1
Basal plate height	11.3	13.5	10.8	8.7	10.3	11.3	8.0	10.0	15.0	12.2	8.0	10.6	13.8	10.8	13.2	9.8	9.8	11.2	9.5	7.1	7.1	7.1
Basal plate width	12.8	15.6	13.9	10.1	11.0	12.0	10.0	10.1	23.4	13.4	8.3	11.4	13.6	11.8	15.0	10.0	10.0	9.4	8.2	8.2	8.2	8.2
Radial plate height	7.7	10.2	10.0	8.5	7.4	9.2	7.6	4.9	9.6	7.6	5.3	9.2	10.9	8.1	9.9	8.0	11.0	9.6	8.3	8.4	5.5	5.5
Radial plate width	13.8	17.2	18.8	12.3	15.0	18.4	17.6	17.6	25.3	17.0	13.0	13.3	18.4	15.5	12.9	15.0	18.0	18.0	13.6	9.4	9.4	9.4
Arm facet width	10.0	10.1	10.4	8.9	9.2	12.0	10.3	9.2	8.0	15.5	10.9	6.4	8.1	11.2	10.8	10.1	8.4	9.3	11.1	9.6	8.0	6.2
Arm length	74.4	101.0	120.0	77.3	80.2	109.0	109.0	82.0	82.1	57.8	109.0	81.6	60.0	99.4	100.0	86.3	86.3	86.3	86.3	86.3	86.3	86.3
Stem diameter	8.5	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0

1, UCWM 15816; 2, ISM 1805; 3, AMNH 7161/5; 4-13, UCWM 8932 A-G, 8931, 8904, 51280; 14-17, YPM 22751 A, B, 6451 A, B; 18, IDG E1158; 19, NYSM 11472; 20-21, UC 25024 A, B; 22, WC 20.

and slightly higher, hexagonal, supported almost entirely by CD basal but also by distal left edge of BC basal, upper surface sloping, supporting two series of anals that superficially resemble Brr; distal portion of anal tube unknown. IBrr decreasing in width uniformly distally. IB_{r1} wider than long, IB_{r4} axillary, arms not preserved above IA_{xx}.

Remarks. The conical dorsal cup of *Barycrinus neglectus* more closely resembles forms of *Poteriocrinites* than typical species of *Barycrinus*; however, the rounded IBrr and depressed edges of the BB and RR indicate that it is similar to specimens of the latter genus. The peculiar structure of the CD interray and gaping sutures are unknown in other forms assigned to this genus and it is possible that this species should be assigned to a new genus, but as it is represented by only one incomplete specimen its placement into *Barycrinus* is retained with question.

Type. The holotype and only known specimen in UCWM no. 6489 from Crawfordsville.

Dimensions. Measurements of the holotype are shown on Table 9.

TABLE 9. Measurements of *Barycrinus? neglectus* in mm.

Measurements	Specimen	
	UCWM 6489 (holotype)	
Dorsal cup height	11.4	
Dorsal cup width	12.1	
Infrabasals height	4.0	
Infrabasal circlet width	6.7	
Basals height	4.0	
Basal circlet width	8.2	
Radials height	3.5	
Anal X height	5.2	
Anal X width	4.2	
Stem diameter	3.4	

[*Barycrinus pentagonus* WORTHEN, 1873]

BASSLER & MOODEY (1943, p. 92, 318) reported that specimens of this species were found in the Crawfordsville beds, but published descriptions fail to confirm this and no specimens referable to this species were found in material available for study.

Barycrinus princeps MILLER & GURLEY, 1890

Plate 1, fig. 14

Barycrinus princeps MILLER & GURLEY, 1890 p. 368, pl. 9, fig. 2, 3 (author's ed., p. 52); MILLER, 1892b, p. 674, fig. 1212, 1213.

Diagnosis. Interbasal depressions distinct but small, sides of RR not depressed; anal X and RA present, arms 12, regularly tapering distally, armllets bearing ramules.

Description. Dorsal cup bowl-shaped, medium-sized, with truncated base, plates smooth to slightly granulose. IBB small, subhorizontal at base; BB nearly as wide as long; RR almost twice as wide as long, rounded, pentagonal, R facet almost two-thirds width of plate, concave, uniformly outward sloping. Anal X small, pentagonal, nearly in line with RR; RA about half the size of anal X, quadrangular, in normal lower oblique position to the C radial. Anal tube unknown. Arms uniformly tapering distally; IBrr wide, 2 in A, C, and D rays, 6 in B and E rays; one bifurcation on the outside occurs on the IBBr₄; armllets given off alternately, commonly at intervals of

2 plates, near distal extremities SAxx bear armllets about equal to size of arms.

Remarks. *Barycrinus princeps* most closely resembles *B. hoveyi*, which also occurs in the Crawfordsville beds, but it can be distinguished by its smaller dorsal cup, less distinct depressed interbasal and interradial areas, and arm structure.

Type. MILLER & GURLEY's holotype is UCWM no. 6167.

Occurrence. This species has been reported only from the Crawfordsville crinoid beds and judging from the few specimens available for study it was comparatively rare.

Material. Besides the holotype, only a single specimen (UCWM no. 8910) was available for study.

Dimensions. Measurements are shown in Table 10.

TABLE 10. Measurements of *Barycrinus princeps* in mm.

Measurements	Specimen	
	UCWM 6167	UCWM 8910
Dorsal cup height	14.2	15.0
Dorsal cup width	20.0	
Infrabasals height	3.0	4.1
Infrabasals width	4.1	4.8
Basals height	7.7	8.9
Basals width	7.4	9.2
Radials width	12.0	12.5
Anal X length	4.4	5.5
Anal X width	5.0	7.3
Arm length	52.0	56.2
Stem diameter		5.8

[*Barycrinus stellifer* S. A. MILLER, 1892]

BASSLER & MOODEY (1943, p. 92, 319) have reported this species from Crawfordsville but this could not be confirmed.

[*Barycrinus tumidus* (HALL), 1858]

BASSLER & MOODEY (1943, 93, 320) have reported specimens of this species found in the Crawfordsville beds but published descriptions do not list this locality.

Genus PELLECRINUS Kirk, 1929

[Miss. (Keokuk), Ky., Ind.]

Much nomenclatural confusion has been associated with the single species assigned to this genus, and as a result most specimens in the various collections available for study are incorrectly labelled *Vasocrinus hexadactylus*. For nearly 50 years paleontologists incorrectly assigned Crawfordsville specimens to this genus, and not until 1929 was the problem finally resolved by KIRK. In summary, LYON (1857) proposed *Vasocrinus* for reception of two Devonian species (*V. valens* and *V. sculptus*), but he failed to designate a type-species. WACHSMUTH & SPRINGER (1879-1880) subsequently designated HALL's *Cyathocrinus lyoni*, which is a synonym of LYON & CASSEDAY's *C. hexadactylus*. They stated (p. 95), "In reconstructing the genus, we prefer to make *Vasocrinus Lyoni* (*Cyathocrinus Lyoni* Hall), from Crawfordsville,

the type, because it is more perfectly preserved in the arm portion. . . .” Farther on (p. 96) they state that “Lyon’s name and Casseday’s has precedence, but being specifically as well as generically incorrect . . . we adopt Prof. Hall’s later name.” These actions are incorrect because according to the rules of nomenclature they were forced to (1) pick one of LYON’S two original forms as the type-species, and (2) LYON’S & CASSEDAY’S species (*C. hexadactylus*) has precedence, regardless of whether or not it was properly described. All subsequent authors until 1929, who defined and discussed *Vasocrinus* followed WACHSMUTH & SPRINGER’S concept of the genus and not LYON’S. Thus, many Crawfordsville specimens were incorrectly labelled *V. hexadactylus* following WACHSMUTH & SPRINGER’S definition. Finally, KIRK (1929, p. 1, 2, 15, 16) reviewed the whole problem and proposed *Pellecrinus* for reception of LYON & CASSEDAY’S *Cyathocrinus hexadactylus*.

Pellecrinus hexadactylus (LYON & CASSEDAY, 1860)
KIRK, 1929

Plate 1, fig. 15; pl. 2, fig. 6, 10, 11; text-fig. 21-3

Cyathocrinus hexadactylus LYON & CASSEDAY, 1860, p. 74.

Pellecrinus hexadactylus KIRK, 1929, p. 15.

Cyathocrinus lyoni HALL, 1861a, p. 298; 1861b, p. 5; 1872, pl. 5, fig. 12, 13.

Barycrinus lyoni MEEK & WORTHEN, 1868b, p. 340.

Diagnosis. Dorsal cup low, broadly bowl-shaped; arms long, relatively slender; anal tube stout, extending about half of height of arms.

Description. Dorsal cup plates smooth to finely granulose, relatively thin. IBB small; BB very large, about as high as wide, smooth; RR very large, nearly twice as wide as high, upper sides long, R facet one-third to one-half width of RR. Commonly two anals in cup, rarely one; anal X heptagonal, large, nearly same size as RR and supporting 3 tube plates; RA when present large, only slightly smaller than BB, quadrangular. Anal tube stout, a median line of large plates extends up tube on posterior side, remainder of tube composed of smaller

plates; anal opening at apex. Arms 10, long, relatively slender, each bifurcating once, IBRR₃ axillary; armlets borne alternately at intervals of 2 Brr, relatively large, bearing ramules. Stem large, round, composed of alternating wide and narrow ossicles, lumen subcircular.

Remarks. *Pellecrinus hexadactylus* most closely resembles *Barycrinus hoveyi*, but it differs in having much thinner plates, smaller IBB, larger BB, and much narrower R facets. Also its arms are longer and more slender, with single bifurcations occurring on IBRR₃ and the stem lacks the distinct pentalobate arranged ossicles characteristic of *Barycrinus*.

Curatorial Problems. As discussed above, considerable nomenclatural confusion has resulted in misidentification and improper labelling of many specimens belonging to this species. Specimens labelled *Vasocrinus lyoni*, *V. valens*, *V. hexadactylus*, *Barycrinus lyoni*, and *Cyathocrinus hexadactylus* present in the Crawfordsville beds should be referred to *Pellecrinus hexadactylus*.

Type. LYON & CASSEDAY’S holotype is USNM no. S-2337. The location of HALL’S type and figured specimen of *Cyathocrinus lyoni* is not known; however, a plaster cast of this specimen is UCWM no. 15763.

Occurrence. Judging from the number of specimens available for study, this species was moderately abundant in the Crawfordsville beds. It is also known from the Ft. Payne Chert of Hardin County, Kentucky.

Material. In addition to plaster casts of types, the following specimens were available for study: UCWM nos. 8915A-E, 8025, 18478A,B, 51821; ISM (IGS) nos. 1807A,B; WC nos. 3, 15.

Dimensions. Measurements of *Pellecrinus hexadactylus* are shown on Table 11.

Family CYATHOCRINITIDAE Roemer, 1854
(Bassler, 1938)

[*nom. subst.* BASSLER, 1938, p. 25 (*pro* Cyathocrinitidae ROEMER, 1854, p. 226)]

[? Ord.-Perm.]

Genus CYATHOCRINITES MILLER, 1821

[Sil.-Perm., Cosmop.]

One species (not *Cyathocrinites multibrachiatus* LYON & CASSEDAY, 1859), representing this somewhat broadly defined genus was extremely abundant in the Crawfordsville beds, but the other forms are known from only one or a few specimens. Two of this latter group (*C. bene-*

TABLE 11. Measurements of *Pellecrinus hexadactylus* in mm.

Measurements	Specimen														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dorsal cup height	22.0	24.0	24.3	8.0	29.0	20.0		23.2	30.0		26.3		26.0		22.5
Dorsal cup width	38.8	41.8	40.1	14.0				59.2					41.5		28.0
Basal height	14.6	16.0	13.0	4.8	15.0	13.1	17.1	14.6	16.1		15.2	12.5	15.2	14.0	13.0
Basal width	14.7	13.4	13.2	4.9	18.0	13.2	18.0		14.9		15.9	11.9	14.3	14.0	13.3
Radial height	10.8	9.3	10.9	3.0	11.0	9.9	10.2	11.4	12.8	12.2	9.0	8.0	9.0	9.8	9.0
Radial width	18.4	18.5	17.0	6.0	23.1	17.4	20.1	13.0	21.2	22.1		18.0	21.0		18.1
Arm facet width	8.0	9.1	8.5	3.2	8.8	7.4	9.2	7.5	10.8	9.6		9.0	9.8	7.7	8.8
Arm length	71.7	81.9	60.0	45.2		102.0	83.0	103.2						79.4	
Stem diameter		8.0	7.0	2.5	8.4	5.6	11.0		10.0	10.0			7.5	8.0	7.1

1, USNM S2337; 2-11, UCWM 15763, 8915 A-E, 8025, 18478 A, B, 51821; 12-13, ISM 1807 A, B; 14-15, WC 3, 15.

dicti and *C. insperatus*) are so poorly defined and illustrated that considerable doubt exists whether or not they represent true species. *C. poterium* was originally defined by characters that resulted from abnormal growth, but additional specimens showing the actual features of the species indicate that it is a well-defined group. Finally, *C. opimus* and *C. multibrachiatus* represent distinct species, but the latter, peculiarly, has many highly variable characters that in other forms are considered constant and taxonomically important. Rather than taking a liberal approach in defining these forms, which would result in proposing several new species, I have been conservative and considered specimens with divergent characters as merely representing morphological variants of a single form.

Specimens of this genus are most likely to be confused with those of *Poteriocrinites* and *Barycrinus*, which also occurred in the Crawfordsville beds. The former can be readily distinguished by its conical dorsal cup, more than one anal plate in the CD interray, prominent and thin-plated anal tube, and pinnulate arms. *Barycrinus* has a more robust and thick-plated cup, commonly a RA, invariably 2 IBrr, and more rounded arms that have very narrow Amb grooves. Also, it has a stem that is divided longitudinally into 5 sections.

Cyathocrinites benedicti (MILLER, 1892)

BASSLER & MOODEY, 1943

Cyathocrinus benedicti MILLER, 1892a (adv. publ. 1891), p. 658, pl. 9, fig. 7.

Cyathocrinites benedicti BASSLER & MOODEY, 1943, p. 388.

Remarks. No specimens resembling the published description of this species were available for study. Considerable confusion exists concerning the locality from which MILLER obtained his type and the only known specimen. Following his description he states, "Found by A. C. Benedict, in the Niagara Group, at Hartsville, Indiana, and now in his collection." BASSLER & MOODEY (1943, p. 388) stated that this is not the type locality, but rather the specimen was found at Crawfordsville. According to records of the U.S. National Museum, MILLER's type (USNM no. S-2477) is labelled from Crawfordsville, Indiana. MILLER's description is as follows:

Calyx subturbinate, height and width subequal, truncated below, plates thick, convex; sutures depressed and angles sunken; surface granular. Basals [IBB] small, forming a low pentagonal cup. Subradials [BB] large, not of uniform size, height and width subequal, highly convex, obscure or undefined ridges radiating toward the middle of the sides, angles deeply sunken. Radials larger than subradials, wider than high, sunken at angles and the lateral sutures, except at the projecting rim at the top, most convex at the brachial sutures and the rim or projecting flange on the superior lateral sides. Articulating scar [R facet] about two-thirds the width of a plate, broadly rounded and directed obliquely outward. Azygous plate [anal X] rather large, truncates a subradial and gradually ex-

pands to the top of the first radials [RR]. The plates are very thick at the top of the calyx, and the thickness is maintained for support of the interradials [since no such plates exist in this genus, possibly he was referring to interambulacra] by a projecting flange. The angles for the support of the interradials are quite obtuse. Arms and column unknown.

Dimensions. The following measurements were made on a plaster cast of MILLER's holotype (USNM no. S-2477): height of dorsal cup, 11.0 mm.; width of dorsal cup, 17.2 mm.; height of posterior B, 5.6 mm.; width of same, 7.0 mm.; height of C-radial, 5.7 mm.; width of same, 6.6 mm.; width of R facet on same, 3.7 mm.; maximum width of anal X, 5.0 mm.

?*Cyathocrinites insperatus* (LYON, 1869)

BASSLER & MOODEY, 1943

Cyathocrinus insperatus LYON, 1869, p. 457, pl. 27, fig. k (as *Cyathocrinus tenuibrachiatus* on plate).

Cyathocrinites insperatus BASSLER & MOODEY, 1943, p. 392.

Cyathocrinus insperatus (misspelling) WACHSMUTH & SPRINGER, 1886, p. 225 (p. 150).

Remarks. LYON's original description is as follows:

The body below the free rays is nearly as wide as high-obconical in form; above the free rays the proboscis is greatly expanded, being nearly as wide, and longer than the body below. The proboscis, or rather, sack, is composed of several rows of large pieces, truncated on both sides, forming a sharp angular point, by which the rows are joined; the pieces in adjacent rows alternating one above the other of those in the adjoining rows.

The plates of the calyx are very thin; basal pieces [IBB] long; the first radials [RR], subradials [BB], and the first two anal pieces are nearly equal in size. The arms long; very small; bifurcate on the summit of the second small first radial; giving off additional branches on the third piece above the branch below [IIBr₃], three or four times. These branches also bifurcate. The precise arrangement of these branches is not clearly made out, owing to the condition of our specimen. The free rays do not appear to have been provided with pinula; they are round, composed of a single row of short pieces, nearly of equal size.

Size of Specimen

	Inches
Diameter of body at base of free arms	0.25
Height of free rays	0.27
Height of sack above second anal piece	0.50
Diameter of sack	0.35 to 0.40
Length of free arms ? width across arms	0.45 to 0.50

Comparison of the above description with LYON's illustration, which bears the name *C. tenuibrachiatus*, n. sp., suggests that either the drawings are not accurate or that his description is incorrect. Some doubt exists, in my opinion, that his illustration is of the specimen he described—although in certain characters it is very similar. As shown on the illustration the arms bifurcate on the IBrr₂₋₃ not at top of IBrr₁ (second first radial of LYON's) and the next bifurcation occurs on the IIBrr₅₋₆ not IIBr₃ as indicated in description. The arms are reported to be 0.27 inches long and the height of the anal tube 0.50 inches, but this size relationship does not exist according

to his figure. Further, the two anal plates referred to are unknown in *Cyathocrinites*, but it is very possible that he misidentified a broken piece of a R or B for an anal. No mention of the stem, which appears on the figure was made although LYON invariably described the stems in his description of new species.

Because of these inconsistencies and as the description is not sufficient for specific identification, the validity of this species is questioned. This species, if it existed, must have been exceedingly rare; however, the slab illustrated by LYON contains two specimens—a remarkable coincidence.

Type. LYON's holotype is USNM no. S-2487. A plaster cast in MOORE's collection of plaster casts which bears this number and labelled *C. insperatus*, has no resemblance to LYON's description and illustration.

Cyathocrinites multibrachiatus (LYON & CASSEDAY, 1859)
BASSLER & MOODEY, 1943

Plate 2, fig. 2, 3; pl. 3, fig. 4, 5, 10, 11; text-fig. 21-1

Cyathocrinites multibrachiatus LYON & CASSEDAY, 1859, p. 245; HALL, 1872, pl. 5, fig. 3; WACHSMUTH & SPRINGER, 1885, pl. 4, fig. 6, 7a, 7b; 1897, p. 96, 115, pl. 3, fig. 4; BATHER, 1900, p. 174, text-fig. 89-1, 2.

Cyathocrinites multibrachiatus BASSLER & MOODEY, 1943, p. 393.

Cyathocrinites multibrachiatus var. LYON & CASSEDAY, 1859, p. 245.

Cyathocrinites multibrachiatus var. *squarrosa* HALL, 1872, pl. 5, fig. 4-6, footnote.

Cyathocrinites arboreus MEEK & WORTHEN, 1865b, p. 160; 1868, p. 520, text-fig.

Poteriocrinites carinobrachiatus QUENSTEDT, 1885, p. 950, pl. 76, fig. 11.

Diagnosis. Dorsal cup rather large, bowl- or slightly globe-shaped; plates smooth to highly nodose, slightly convex; arms variable.

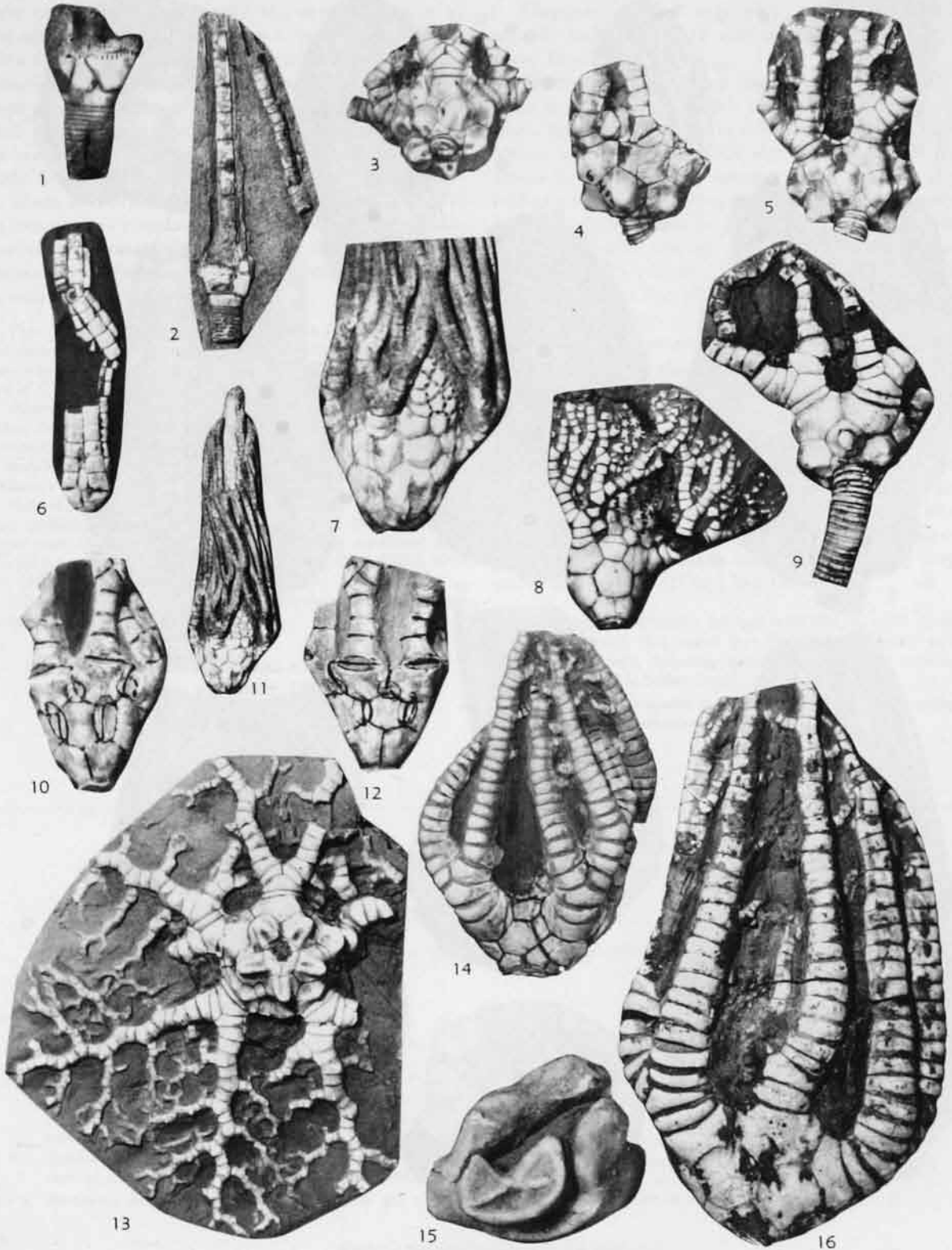
Description. Crown medium-sized to large; dorsal cup plates thick. IBB rather large; BB large, commonly CD-basal distinctly larger than others; RR large, twice as wide as high, upper lateral surfaces bevelled, with narrow rim commonly seen in lateral view; R facets one-half to two-thirds width of plate. Anal X large. Anal tube rather stout, proximal portion thinner, anal opening at apex covering about a third of the summit of the tube. Arms extremely variable in size and arrangement; IB_{rr1-7}, irregular in size but commonly longer than wide; bifurcations numerous, at intervals of 1 to 9 Brr, some branches of dichotome remain single while the adjacent branch bifurcates 4 to 5 times; shape and length of arm varies between individual specimens, some have short, thick arms while others have longer, more slender ones. Stem round, proportionally small.

Remarks. *Cyathocrinites multibrachiatus* is represented by an unusually large number of specimens with variable characteristics. As a result, a conservative approach has been taken in the definition of this form. Two varieties, or better, morphologic groups are represented: (1) specimens having a rather large, nodose, somewhat globe-shaped dorsal cup and thick, short arms; (2) those with a smooth, bowl-shaped cup and longer, more slender arms. By themselves these would surely be interpreted as representing two distinct species, and in fact HALL did propose a variety (*C. multibrachiatus* var. *squarrosa*) for the former group. However, study of nearly 50 specimens indicates that the shapes of the dorsal cups and size and arrangement of arms are highly variable. Numerous individuals have smooth cups with rather short, thick arms. Others possess nodose cups with long, slender arms. Both of these variants in turn are represented by dorsal cups that are bowl- or globe-shaped or of some

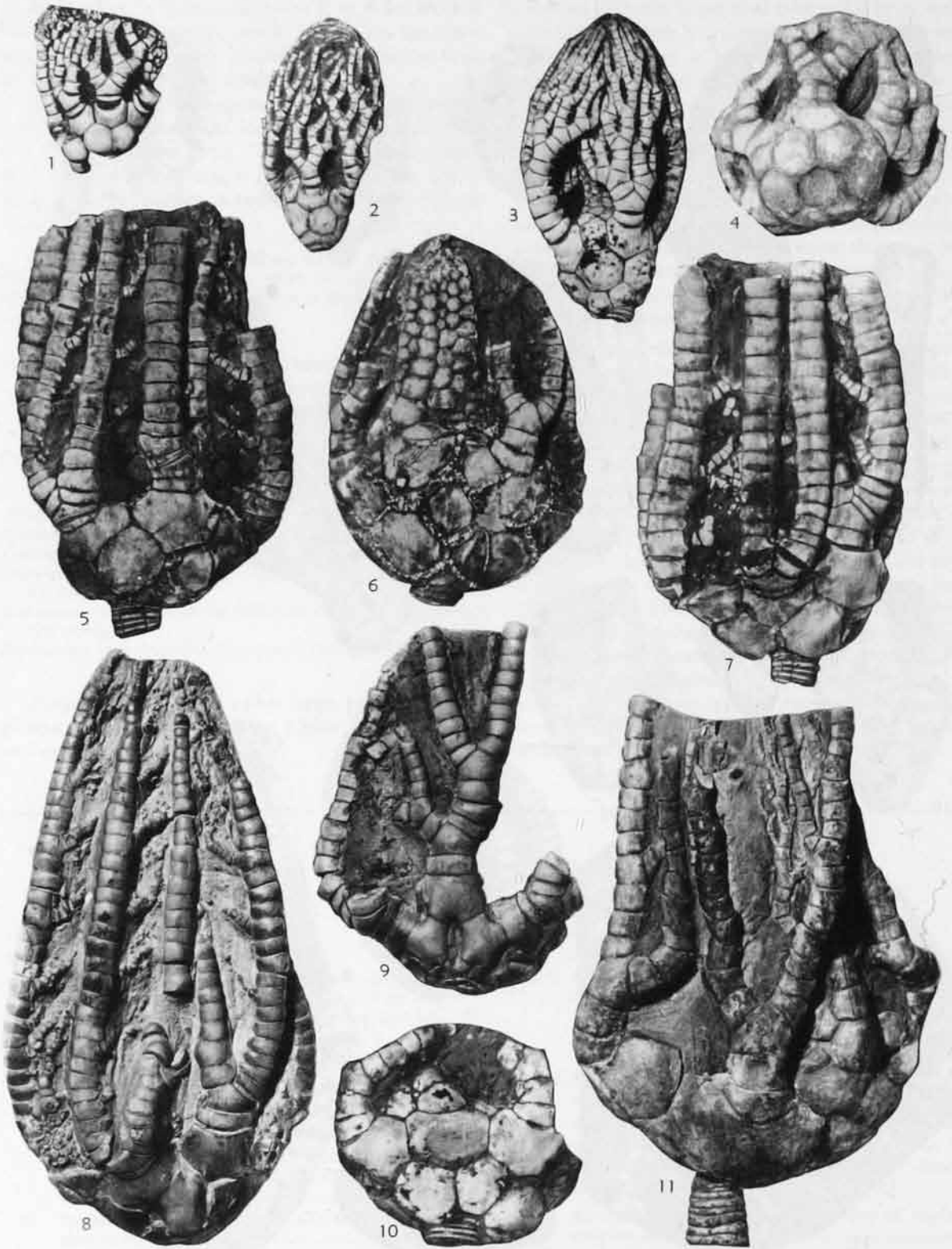
EXPLANATION OF PLATE 1

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE
1, 2. <i>Eucatillocrinus bradleyi</i> (MEEK & WORTHEN); 1, E ray view of holotype (ISM 2400), $\times 2$; 2, A ray view of specimen (UCWM 51827) showing long anal tube	68
3-5, 9, 13. <i>Barycrinus asteriscus</i> VAN SANT, n. sp.; 3, oblique C ray view of incomplete crown (YPM 6452E); 4, D ray view of dorsal cup and small parts of two arms (YPM 6452D); 5, slightly oblique BC view of incomplete crown (YPM 11482); 9, D ray view of incomplete crown and attached stem (WC 64); 13, dorsal view of well-preserved crown (holotype) showing stelliform basal circlet and pattern of arm branching (YPM 6452)	73
6. <i>Synbathocrinites swallowi</i> HALL; CD, view of incomplete crown (UCWM 8908)	71
7, 8, 11. <i>Parisocrinites crawfordsvillensis</i> (S. A. MILLER); 7, 8, D ray and CD views of holotype of MILLER & GURLEY's <i>Poteriocrinites circumtextus</i> , $\times 2$, $\times 1$; 11, D ray view of holotype of MILLER & GURLEY's <i>Poteriocrinites subramosus</i> (UCWM 6255B)	72
10, 12. <i>Barycrinus? neglectus</i> MILLER & GURLEY; lateral views of holotype (UCWM 6489)	76
14. <i>Barycrinus princeps</i> MILLER & GURLEY; CD view of well-preserved crown, holotype (UCWM 6167)	77
15. <i>Pellecrinus hexadaetylus</i> (LYON & CASSEDAY); distal articular surface of IB _{rr1} (UCWM 51831), $\times 3$	78
16. <i>Barycrinus hoveyi</i> (HALL); B ray view of nearly complete crown (YPM 22751B)	74



VAN SANT & LANE—Crawfordsville Crinoids



VAN SANT & LANE—Crawfordsville Crinoids

intermediate outline. In addition, numerous different patterns of ornamentation, each grading into another are present. If the variable features or groups of them were considered taxonomically important then four or five additional species would have to be proposed and the allowable limits of certain characteristics would be impossible to define because they grade into one another imperceptibly. Thus, it seems more logical to consider these individuals as representing a single, highly variable species rather than a number of forms that cannot be precisely defined.

MEEK & WORTHEN'S *Cyathocrinus arboreus* belongs to an intermediate morphological group, which has smooth, bowl-shaped dorsal cups and rather short, stout arms. QUENSTEDT'S *Poteriocrinites carinobrachiatus* has a smooth cup and rather long arms.

Type. Specimens used by LYON & CASSEDAY for their description and drawn for their unpublished plates are USNM no. S-2489A,B. HALL'S hypotypes are AMNH no. 7161/1. MEEK & WORTHEN'S holotype of *C. arboreus* is ISM no. 10141 (IDG no. X-63).

Occurrence. This species was abundant in the Crawfordsville crinoid beds and specimens from Indian Creek are known, but not previously reported. Judging from number of specimens available, *C. multibrachiatus* was one of the most abundant inadunate species at Crawfordsville.

Material. In addition to numerous unprepared specimens that were available, 48 well-preserved specimens were studied. Besides plaster casts of some of the types, the following specimens were selected for measurements: UCWM nos. 8905A-E, 8916, 15234; YPM nos. 6450A-E; NYSM nos. 11473, 11615, 11616.

Dimensions. Measurements of selected specimens of *Cyathocrinites multibrachiatus* are shown on Table 12.

**Cyathocrinites opimus (MILLER & GURLEY, 1890)
BASSLER & MOODEY, 1943**

Plate 2, fig. 1

Cyathocrinus opimus MILLER & GURLEY, 1890, p. 348 (author's ed., p. 28), pl. 5, fig. 5.

Cyathocrinites opimus BASSLER & MOODEY, 1943, p. 394.

Diagnosis. Dorsal cup very small, BB inflated, smooth; each division of arm branching 5 to 7 times above IAXx.

Description. Dorsal cup low, bowl-shaped, twice as wide as high; plates smooth to slightly granular. IBB small, only slightly visible in side view; BB large, highly convex and protuberant; RR slightly rounded, R facet almost as wide as plate, suture gaping. Anal X about half as wide as RR, slightly rounded. Anal tube extending almost as high as arms, consisting of a series of rather large plates, with opening at apex. Arms robust, short; commonly 2 IBrr, rarely 3 in each ray; axils considerably longer than other arm plates; Brr slightly constricted near middle giving them an angular appearance, subequal in size following bifurcations. Stem round.

Remarks. The short, broad dorsal cup and inflated large BB distinguish *C. opimus* from all other described species of *Cyathocrinites*. WACHSMUTH & SPRINGER (1897, p. 96, 114; pl. 3, fig. 2; pl. 7, fig. 12 a, b) illustrated and discussed features of the anal tube and Ambb of specimens which they referred to as *C. brevisacculus*, but they neither described the crown nor stated its age or where it was found. According to their illustrations it appears similar to *C. opimus*, but its arms are considerably longer and at least one ray (*D* ray) has 5 IBrr.

Type. MILLER & GURLEY'S holotype is USWM no. 6172. In their original description they stated that the type was found in the Crawfordsville beds; however, according to museum records it actually was found at Indian Creek.

Occurrence. This species is reported only from Borden rocks at Indian Creek and Crawfordsville.

EXPLANATION OF PLATE 2

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE
1. <i>Cyathocrinites opimus</i> (MILLER & GURLEY), Indian Creek; <i>A</i> ray view of holotype (UCWM 6172)	81
2,3. <i>Cyathocrinites multibrachiatus</i> (LYON & CASSEDAY), ?Indian Creek; 2, <i>C</i> ray view of crown (YPM 6450A); 3, <i>CD</i> interray view of essentially complete crown (UCWM 19197)	80
4. <i>Cyathocrinites poterium</i> MEEK & WORTHEN; <i>A</i> ray view of crown obliquely from below (UCWM 8941)	82
5,7-9. <i>Barycrinus hoveyi</i> (HALL); 5,7, <i>EA</i> interray and <i>C</i> ray views of crown showing stout arms and wide-spaced short armllets (UCWM 51820); 8, <i>A</i> ray view of well-preserved crown (UC 52024A); 9, <i>B</i> ray view of another crown (UC 25024B)	74
6,10,11. <i>Pellecrinus hexadactylus</i> (LYON & CASSEDAY); 6, <i>CD</i> interray view showing structure of anal sac with anal vent near summit (UCWM (8915A)); 10, <i>CD</i> interray view of cup showing large anal X (IDG E1403); 11, <i>D</i> ray view of crown (UCWM 18478)	78

TABLE 12. *Measurements of Cyathocrinites multibrachiatus in mm.*

Measurements	Specimen																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dorsal cup height	11.3	14.7	12.9	13.9	14.0	14.5	16.4	11.5	14.7	13.8	13.2	16.5	13.5	16.1	14.0	12.6	12.4	13.3	14.4	
Dorsal cup width	14.4	18.0	17.2	19.2	17.4	19.6	14.5	19.3	18.0	16.0	17.9	14.0							17.8	
Basals height	6.8	8.7	8.4	8.0	8.0	8.6	8.0	6.9	8.9	7.4	10.0	8.5	11.1	7.1	9.2	7.6	6.9	6.8	7.1	
Basals width	7.1	8.9	8.2	8.3	8.5	8.0	8.1	6.2	7.3	7.3	8.0	6.9	10.9	6.4	8.0	7.2	6.2	6.1	6.8	
Radials height	3.2	5.3	4.8	4.0	5.1	5.3	5.0	3.5	4.0	5.0	4.8	7.5	4.6	5.3	4.7	4.7	5.0	3.9	4.9	
Radials width	6.3	7.8	6.9	8.6	7.4	8.7	9.1	8.0	7.7	6.5	12.0	7.2	9.9	9.4	6.8	7.1	6.4	7.0		
Arm facet width	4.3	5.0	3.5	4.6	3.6	5.1	4.9	5.0	4.4	4.9	4.5	3.9	6.5	3.9	5.4	3.1	3.7	3.9	4.0	
Arm length		45.2	42.0			46.0	48.0	35.0	57.7	47.8	52.6	42.3	52.5	42.0	52.1	48.0	43.5	38.0	45.0	
Stem diameter	3.4			5.1	4.8	6.4		4.1		5.0		5.7	7.1	4.4	6.1	4.9	4.8		5.0	

1-2, USNM S2489 A, B; 3-4, AMNH 71601/1 A, B; 5, ISM 10141; 6-12, UCWM 8905 A-E, 8916, 15234; 13-17, YPM 6450 A-E; 18-20, NYSM 11473, 11615, 11616.

Material. Besides the holotype the following specimens from Crawfordsville were available for study: UCWM nos. 8897A,B; 51822.

Dimensions. Measurements of this species are shown on Table 13.

TABLE 13. *Measurements of Cyathocrinites opimus in mm.*

Measurements	Specimens			
	1	2	3	4
Dorsal cup height	8.4	9.2	8.9	12.2
Dorsal cup width		10.2	10.1	
Basals height	5.5	5.3	6.3	8.6
Basals width	5.0	5.1	6.0	7.6
Radials height	3.0	2.3	3.9	3.9
Radials width	5.7	5.6	6.4	7.0
Arm facets width	5.0	4.7	4.6	4.9
Arm length		28.0	19.0	33.0
Stem diameter	3.4	3.2	3.1	4.0

1-4, UCWM 6172, 8897 A, B, 51822, respectively.

Cyathocrinites poterium (MEEK & WORTHEN, 1870)
VAN SANT (n. comb.)

Plate 2, fig. 4

Cyathocrinus? poterium MEEK & WORTHEN, 1870, p. 24; 1873, p. 489, pl. 12, fig. 4.

Cyathocrinus poterium WACHSMUTH & SPRINGER, 1879 (1880), p. 87.

Cyathocrinites? poterium BASSLER & MOODEY, 1943, p. 394.

Diagnosis. Dorsal cup very low, globe-shaped, greatest width at level of BB; IBrr₁₋₄, relatively large, more distal Brr forming long slender arms.

Description. Dorsal cup somewhat flattened at base; plates smooth to finely granulose; sutures not depressed. IBB moderately small, only slightly inflaring for reception of stem; BB large, forming widest part of cup near their distal edges, curving inward slightly in proximal portion; uniformly convex; RR about same in size as BB; anal X about half the size of RR. Anal tube unknown. Arms long, Brr tapering rapidly above IAXx, second bifurcations occur on IIBrr₂₋₃. Stem impression round; columnals unknown.

Remarks. The low, globe-shaped dorsal cup of this species is not typical of *Cyathocrinites*; however, nature of R facets, presence of a single anal plate and long tapering arms suggests assignment to this genus. MEEK & WORTHEN's type does not agree in all respects to the above description because in two of its rays the arms are unbranched and the IBrr₂₋₄ are flattened. This peculiar feature is unknown in other crinoids and probably resulted from either abnormal growth or post-burial compression. It is possible but not evident in illustration of their type, that the dilated structure actually represents part of the anal tube. A somewhat larger but similar specimen available for study has typical long slender arms, which suggests that the inflated IBrr cannot be considered significant in definition of this species. Because of the small rounded dorsal cup and slender arms MEEK & WORTHEN proposed the generic name, *Saccomopsis* for this species. This assignment was never followed, however.

Type. The holotype is USNM no. S-2500.

Occurrence. This species is known only from the Crawfordsville beds, where it was exceedingly rare.

Material. Besides a plaster cast of the holotype, a single specimen (UCWM no. 8941) was available for study.

Dimensions. Measurements of this species are shown on Table 14.

TABLE 14. *Measurements of Cyathocrinites poterium in mm.*

Measurements	Specimen	
	Cast USNM S2500	UCWM 8941
Dorsal cup height	4.5	4.8
Dorsal cup width		9.8
Basals height	3.4	4.3
Basals width	4.4	4.4
Radials height		2.9
Radials width		6.0
Arms length	19.1	22.5

Suborder DENDROCRININA Bather, 1899

[Ord.-Perm.]

Family BLOTHROCRINIDAE Moore & Laudon, 1943

[Miss.-Perm.]

Genus LEBETOCRINUS Kirk, 1940

[L. Miss. (Border Gp.), Ind.]

Lebetocrinus grandis KIRK, 1940*Lebetocrinus grandis* KIRK, 1940, p. 75, pl. 11, fig. 1-5.

Because nothing can be added to the original description and since KIRK's article is readily accessible, this species is not redescribed and illustrated. Only one of KIRK's specimens was reported as probably from the Crawfordsville beds. The others came from Indian Creek. KIRK indicated that search of crinoid collections at Yale Peabody Museum, Walker Museum (University of Chicago), and Museum of Comparative Zoology (Harvard College) was unsuccessful in obtaining additional specimens, and none were found in the material available for this study.

Family ERISOCRINIDAE Miller, 1889

[Miss.-Perm.]

Genus GRAPHIOCRINUS de Koninck & le Hon, 1854

[L. Carb., N. Am., Eu.; Penn., N. Am.; Perm.; Timor]

Graphiocrinus mcadamsi (MEEK & WORTHEN, 1873)

WACHSMUTH & SPRINGER, 1880

Plate 3, fig. 3

Poteriocrinites (*Scaphiocrinus*) *mcadamsi* MEEK & WORTHEN, 1873, p. 495, pl. 15, fig. 2.*Graphiocrinus mcadamsi* WACHSMUTH & SPRINGER, 1879 (1880), p. 123.

Diagnosis. Dorsal cup truncate, bowl-shaped above IBB; IBB upflaring; Brr cuneate, slightly constricted in middle; IAXx and IIBrr₁, much longer than other arm plates.

Description. Dorsal cup plates moderately thick, smooth, uniformly convex with distinct sutures. IBB moderately large; BB small, much wider than long; RR nearly twice as large as BB, considerably wider than high. Anal X about same size as BB, supported by truncated upper surface of CD basal. Arms rather long and slender, IBr₁ axillary, nearly twice as high as wide, Brr wedge-shaped. Stem small, consisting of alternating narrow and wide ossicles, conspicuous larger ossicles at intervals of 8 to 10.

Remarks. *Graphiocrinus mcadamsi* somewhat resembles *G. simplex* (HALL), 1858 from the Burlington Limestone in size and arrangement of arms; however, this older form has a lower bowl-shaped cup, proportionally larger RR, lacks large IIBrr₁, and has shorter, more rounded wedge-shaped Brr.

Type. MEEK & WORTHEN's type is presumed to be lost, and thus NYSM no. 11475 is herein selected as the neotype.

Occurrence. This species is known from the Keokuk Limestone of Jersey County, Illinois, and Borden rocks at Crawfordsville.

Material. Only the neotype was available for study. This specimen, although slightly crushed in the CD interray, is representative

of the species and very similar to the specimen used for definition of the species.

Dimensions. The neotype has the following dimensions: height of dorsal cup, 5.8 mm.; height of B, 2.9 mm.; height of IAX, 3.2 mm.; height of IIBrr₁, 2.7 mm.; height of IIBrr₂, 1.4 mm.; length of arms preserved, 29.8 mm.; width of stem, 1.6 mm.

Family GLOSSOCRINIDAE Goldring, 1923

[Dev.-Miss.]

Genus CYDROCRINUS Kirk, 1940

[Miss. (Keokuk), Iowa, Ind.]

Cydrocrinus is represented by only a single known specimen from Crawfordsville; however, other specimens undoubtedly also occurred in these beds. Some specimens labelled *Pachylocrinus* in the various collections probably are referable to *Cydrocrinus*. These genera superficially resemble one another, but the turbinate cup, large IBB and endotomous arms in each half-ray sharply contrast with the low truncate bowl-shaped cup and endotomous arms of *Pachylocrinus*.

Cydrocrinus concinnus (MEEK & WORTHEN, 1870)

KIRK, 1940

Plate 3, fig. 14; text-fig. 31-1a-c

Poteriocrinites (*Zeacrinus?*) *concinnus* MEEK & WORTHEN, 1870, p. 26; 1873, p. 490, pl. 14, fig. 5.*Poteriocrinus* (*Pachylocrinus*) *concinnus* WACHSMUTH & SPRINGER, 1879 (1880), p. 116.*Cydrocrinus concinnus* KIRK, p. 325.

Diagnosis. Dorsal cup low cone-shaped, with finely granulose surface, 2 IBrr in each ray, except A ray which has 7; each half-ray branching 5 or more times, except fewer in A ray.

Description. IBB short, less than half the size of the BB, truncate below; BB slightly wider than high; RR short, R facet linear, not gaping. Anal X larger, extending to near upper surface of IAX in D ray; RA large, not deeply inserted between CD and BC basals; RT somewhat smaller; anal tube unknown, arms long, slender, tapering gradually distally, bifurcations common at intervals of many Brr in upper one-half portion of arms, not strongly diverging; Brr somewhat angular, slightly wedge-shaped and broad in lower part, proportionally much narrower and distinctly cuneate in distal portion; pinnules very small. Stem round, proportionally large, composed alternating thick and thin short ossicles.

Remarks. *Cydrocrinus concinnus* resembles *C. coxanus* WORTHEN from Keokuk rocks at Hamilton, Illinois, but it differs in having a much smaller crown, lower dorsal cup with proportionally smaller IBB, and more numerous bifurcations in all half-rays except A ray. Comparison of arm bifurcations are shown in Figure 31.

Type. MEEK & WORTHEN's holotype, labelled *Scaphiocrinus concinnus*, is ISM no. 1808, now in the collection of the Illinois Geological Survey.

Occurrence. This species is known to be represented by only the holotype, which was found at Crawfordsville.

Dimensions. The holotype has the following dimensions: approximate height of dorsal cup, 7.8 mm.; width of cup, 14.6 mm.; height of IBB, 1.8 mm.; height of RR, 2.5 mm.; width of RR, 4.1 mm.; height of IBr₁, 2.4 mm.; length of arm, 66.8 mm.; width of stem, 4.9 mm.

[*Cydropocrinus coxanus* (WORTHEN, 1862) KIRK, 1940]

BASSLER & MOODEY (1943, p. 93, 401) have indicated that this species was reported from Crawfordsville, but this could not be confirmed in published accounts of this species.

Family PACHYLOCRINIDAE Kirk, 1942

[Miss.-Perm.]

Genus ABROTOCRINUS Miller & Gurley, 1890

Abrotocrinus MILLER & GURLEY, 1890a, p. 30; 1890b, p. 350; WANER, 1924, p. 177; SPRINGER, 1926, p. 72.

Revised Description. Dorsal cup low bowl-shaped, broad, with large, somewhat deep basal concavity; IBB small, concealed by stem; BB moderately large, proximal portion forming sides of basal concavity; RR wider than high, R facet extending completely across plate, suture gaping, CD interray relatively narrow; RA large, rather low in cup, supporting RT directly above; anal X commonly elongate, extending above RR. Anal sac rather stout, expanded in apical portion, commonly spinose; anal opening large, anterior, well below summit of tube. Arms long, slender, composed of wedge-shaped Brr; IBr₁ large, axillary except in A ray, which may be atomous or bifurcate once on IBr₄₋₅, other rays commonly endotomous, branching 1, 2 or 3 times on each division above IAXx; Axx conspicuously larger than other Brr, slightly inflated; pinnules long, slender, composed of numerous long subequal pinnulars. Stem pentagonal in proximal portion, becoming rounded subpentagonal a short distance from cup.

Type-species. *Abrotocrinus cymosus* MILLER & GURLEY, 1890 (= *Scaphiocrinus unicus* HALL, 1861, p. 313).

Remarks. According to the original description of *Abrotocrinus*, MILLER & GURLEY misinterpreted the structure of the CD interray, which was not exposed on their specimen of the type-species. In the description the anal X was described as resembling a radial plate and it supported a long series of short plates. These structures do not occur in the CD interray as described but are those typical of the A radial and succeeding atomous Brr. However, because most species subsequently assigned to *Abrotocrinus* represent a distinct group of organisms, the genus is retained with slight modification of the original broadly defined concept of the genus.

Most authors considered *Abrotocrinus* a synonym of *Pachylocrinus* until it was resurrected by SPRINGER (1926), who included all species of *Pachylocrinus*-type

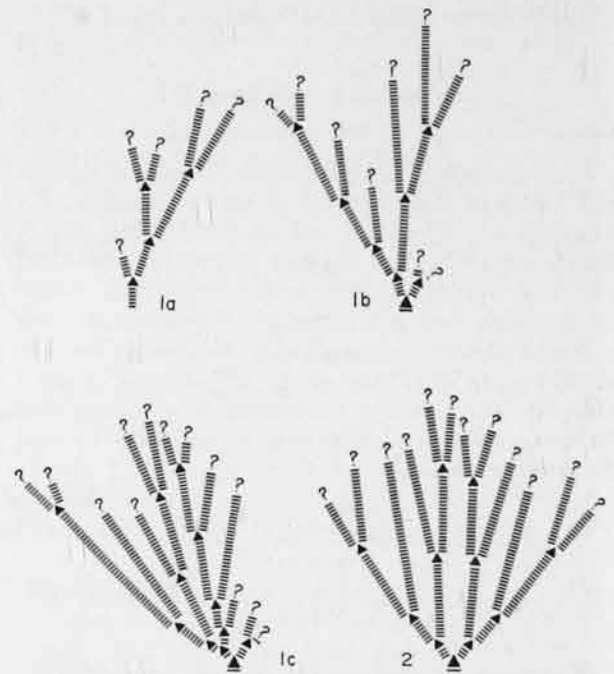


FIGURE 31. Patterns of arm branching in *Cydropocrinus*.—1-a-c. *C. concinnus* showing A, E, and D rays, respectively.—2. Mode of branching observed on unknown ray of *C. coxanus*. [EXPLANATION: Axillary plates designated by triangles; nonaxillary brachials counted in each series represented by bars.]

that have pentagonal stems. This diagnostic feature, which SPRINGER states as being “. . . not a very reliable one . . .,” characterizes most species, but intermediate forms with both angular and round stems and those with only subpentagonal stems are known. However, *Abrotocrinus* is a well-characterized genus that differs from other inadunates in several distinctive features, which have not been previously described.

Study of Crawfordsville specimens of this genus necessitates revision of the designated type-species of *Abrotocrinus*. *A. cymosus* MILLER & GURLEY, 1890 became type for the genus by original designation (monotypy); however, comparison of it with abundant specimens of the Crawfordsville species *A. unicus* (HALL), 1861, indicates that the original type is unquestionably a junior synonym of the latter form. Consequently, *A. unicus* must now be considered the type-species.

Revision of the generic concept of *Abrotocrinus* results in re-allocation of several forms previously referred to the genus. As now interpreted the following species are assigned to the genus: *Scaphiocrinus unicus* HALL, 1861; *Poteroicrinites (Graphiocrinus; Scaphiocrinus) coreyi* MEEK & WORTHEN, 1869; *Poteroicrinus occidentalis* WORTHEN, 1882; *P. orestes* WORTHEN, 1882; and possibly *P. sculptus* WORTHEN, 1882 and *Abrotocrinus ornatus* TERMIER & TERMIER, 1950. The last two

forms are so poorly known that identification of characters now considered diagnostic of the genus cannot be made with assurance. Presence of 2 IBrr in each ray of *P. sculptus* and nature of dorsal cup suggest possible assignment of this form to *Pachylocrinus* or KIRK's *Hylodecrinus*. *Abrotocrinus angustatus* WRIGHT, 1934 has a steep conical cup with large, visible IBB, and a long, slender anal tube. Thus, it cannot be assigned to the genus; seemingly it belongs to KIRK's *Cosmetocrinus* or possibly his *Ascetocrinus*. *Abrotocrinus parviglyptus* LAUDON & BEANE, 1937 and *Scaphiocrinus rusticellus* WHITE, 1863 were assigned by KIRK to his genera *Pelecocrinus* and *Ascetocrinus*, respectively.

KIRK (1941) placed *Abrotocrinus* in his new family Pelecocrinidae seemingly because of the atomous nature of the *A* ray; however, characters judged important in definition of inadunate families suggest that this genus should be assigned to the pachylocrinids.

Abrotocrinus most nearly resembles *Pachylocrinus* but differs in having a much larger, more depressed dorsal cup, relatively longer arms that bifurcate first on IBrr₁ and less frequently above, atomous *A* ray or ray bifurcating once on IBrr₄₋₅, and proximal pentagonal-shaped stem ossicles. *Pelecocrinus* is distinguished by a bowl-shaped cup, with IBB barely visible in side view, horseshoe-shaped R facets, and nearly biserial arranged Brr in some portions of the arms. *Ascetocrinus* differs from *Abrotocrinus* in having a compact narrow crown, less depressed dorsal cup, single IBr in *A* ray, and a slender, short anal tube.

Occurrence. Species now assigned to *Abrotocrinus* have been described from Keokuk rocks of Illinois, Iowa, and Indiana and rocks of Chesteran age in Illinois and Alabama. *A. ornatus* TERMIER & TERMIER was established from fragmentary specimens found in Carboniferous rocks of Morocco (142A).

Abrotocrinus coreyi (MEEK & WORTHEN, 1869)

VAN SANT (n. comb.)

Plate 3, fig. 2, 9

Poteroicrinites (*Graphiocrinus*; *Scaphiocrinus*) *coreyi* MEEK & WORTHEN, 1869b, p. 148.

Poteroicrinites (*Scaphiocrinus*) *coreyi* MEEK & WORTHEN, 1873, p. 494, pl. 15, fig. 1.

Poteroicrinus (*Scaphiocrinus*) *coreyi* WACHSMUTH & SPRINGER, 1879 (1880), p. 112 (p. 335).

Pachylocrinus coreyi BASSLER & MOODEY, 1943, p. 580.

Zeacrinus stimpsoni LYON, 1869, p. 465, pl. 27, fig. m, ml.

Scaphiocrinus lyoni MILLER, 1894, p. 299, pl. 5, fig. 25 (adv. publ. 1892).

Diagnosis. Dorsal cup medium-sized, wide, with broad basal concavity; arms long, very slender, branching once above IAxx; Brr strongly wedge-shaped above IAxx giving arms distinct zigzag outline; stem sub-pentagonal near dorsal cup.

Description. Dorsal cup plates smooth to finely granulose, uniformly convex. IBB small, concealed by stem; BB moderately large, forming sides of basal concavity; RR only slightly larger than BB. R facet gaping, extending nearly whole width of plate, sloping outward. CD interray moderately wide; RA low in cup, slightly elongate; anal X extending above R circlet. Anal tube unknown. Arms long; IBrr₁ axillary except in *A* ray, long, constricted in middle; *A* ray bifurcating once on IBrr₈; second bifurcation in other rays occurring on IBrr₆, arms remaining simple above; Brr round, strongly wedge-shaped above second dichotome, Axx not inflated; pinnules long, slender. Stem only obscurely pentagonal in proximal portion.

Remarks. Shape of dorsal cup and structure of arms of *Abrotocrinus coreyi* indicate that previous assignment of this species to *Pachylocrinus* is erroneous. It can be readily distinguished from *A. unicus* by its smaller size more slender, zigzag-appearing arms, bifurcating *A* ray and less inflated BB and Axx.

Type. MEEK & WORTHEN's holotype could not be located and it is presumed lost. YPM no. 22754A is herein selected as neotype. LYON's holotype of *Zeacrinus stimpsoni* is USNM no. S-2596 and MILLER's type of *Scaphiocrinus lyoni* is USNM no. S-2595.

Occurrence. This species has been reported only from Borden rocks at Crawfordsville.

Material. In addition to the holotype and plaster casts of species considered synonyms, the following specimens were available for study: YPM no. 22754B; ISM (IGS) no. 8313.

Dimensions. Measurements of *Abrotocrinus coreyi* (MEEK & WORTHEN) are shown on Table 15.

TABLE 15. Measurements of *Abrotocrinus coreyi* in mm.

Measurements	Specimen			
	1	2	3	4
Dorsal cup height	5.6	4.7	5.0	6.1
Dorsal cup width	11.2	8.2		13.0
Basals height	3.0	2.8	3.8	4.0
Basals width	4.0		5.0	4.5
Radials height	3.5	2.9	3.2	2.8
Radials width	5.0	4.2	4.9	5.0
Arms length	42.5			38.0
Stem diameter		2.5	3.1	3.0

1, YPM 22754A; 2-3, USNM S2595, S2596; 4, YPM 22754B.

Abrotocrinus unicus (HALL, 1861) SPRINGER, 1926

Plate 3, fig. 1, 6-8, 12, 13; text-fig. 23-2; 32

Scaphiocrinus unicus HALL, 1861a, p. 313 (prelim. note p. 8); 1872, pl. 6, fig. 6; WACHSMUTH & SPRINGER, 1897, pl. 7, fig. 6.

Poteroicrinus (*Scaphiocrinus*) *unicus* MEEK & WORTHEN, 1873, p. 473, pl. 15, fig. 5; 1875, p. 519, pl. 29, fig. 1; WACHSMUTH & SPRINGER, 1879 (1880), p. 114.

Abrotocrinus unicus SPRINGER, 1926, p. 65, 73, pl. 17, fig. 1-3.

Abrotocrinus cymosus MILLER & GURLEY, 1890, p. 350, pl. 5, fig. 2 (author's ed. p. 31).

Diagnosis. Dorsal cup very low, bowl-shaped, with a broad truncated base; small distinct pits at angles of

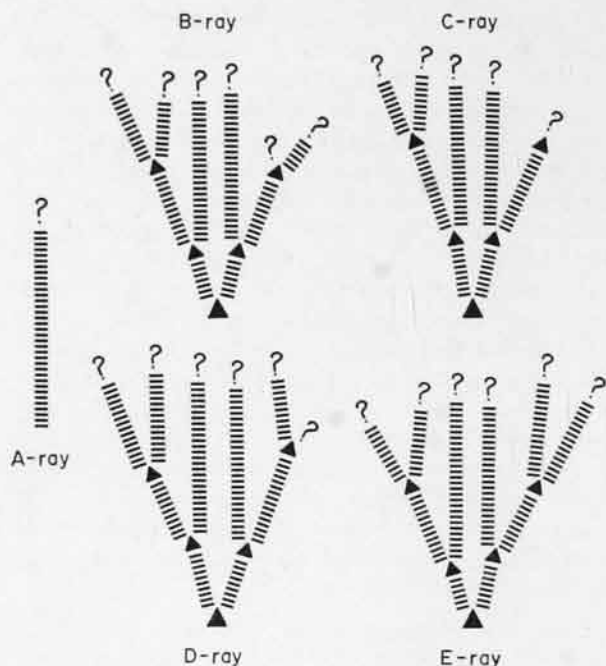


FIGURE 32. Pattern of arm branching in *Abrotocrinus unicus* (USWM no. 51825). [EXPLANATION: Same as text-fig. 31.]

plates; arms long, bifurcating 2 or 3 times in each division; Axx much larger than other Brr, moderately convex; *A* ray atomous.

Description. Dorsal cup much wider than high, plates smooth, with small deep pits at angles of the plates. IBB completely concealed by stem; BB rather large, proximal portion forming sides of basal concavity, commonly slightly inflated; RR larger than BB, nearly twice as wide as high, commonly nearly flat except in distal portion which flares outward, R facet slightly crescentic, suture gaping. *CD* interray relatively narrow; anal X medium-sized, slightly elongate, supporting a single tube plate directly above; RA large, well down in cup, supporting moderately large RT. Anal sac somewhat stout, about half as high as arms, summit commonly inflated and composed of large hexagonal plates, 2 or 3 stout spines projecting upward at distal end; anal opening

rather large, slightly more than half way up tube on anterior side. Arms long, slender, endotomous; IBrr₁ axillary, pentagonal with steeply sloping long upper sides, IBrr₁ of *A* ray subquadrangular, not bifurcating. IIBrr₁ more than twice as large as IIBrr₂; Brr short, distinctly wedge-shaped; second bifurcation on IIBrr₇₋₁₂, third bifurcation in IIBrr₁₀₋₁₅, inner branch remaining simple; pinnules long, slender. Stem pentagonal, near cup, moderately wide.

Remarks. The holotype of *Abrotocrinus cymosus* from Washington County, Indiana, is unquestionably a typical average-sized specimen of *A. unicus*, and thus is considered a synonym herein. This reallocation results in the latter form becoming the type-species of the genus. *Poteriocrinus occidentalis* WORTHEN from Keokuk rocks at Hamilton, Illinois, most closely resembles *A. unicus* and differs only in having less inflated BB and 2 bifurcations in all rays except the *A* ray, which is atomous. The pattern of arm branching on specimens of *A. unicus* is characteristic and constant on all specimens available for study. Only the number of Brr in different series are variable and these seemingly differ within very narrow limits. Figure 32 illustrates the typical mode of branching.

Type. HALL's holotype of *A. unicus* could not be located; however, a well constructed plaster cast of it is UCWM no. 15824. One of MEEK & WORTHEN's hypotypes (1875, pl. 29, fig. 1) is ISM no. 13155 (IDG no. X-1206).

Occurrence. This species has been reported from Borden rocks at Crawfordsville, Indian Creek, and Canton, Indiana. In the Crawfordsville beds it is one of the most abundant inadunate species known.

Material. More than 40 well-preserved specimens of this form were available for study. In addition, numerous other less perfectly preserved specimens were observed. The following 15 specimens were selected for measurements: UCWM no. 15824 (plaster cast of holotype), 51824, 51825, 8914A-D; ISM no. 13155 (IDG no. X-1206, hypotype) IGS (ISM) no. 8195; WC nos. 5, 32; NYSM nos. 11477, 11618, 11619, YPM no. 6443.

Dimensions. Measurements of selected specimens of this species are shown on Table 16.

Genus PACHYLOCRINUS Wachsmuth & Springer, 1880

[L.Miss.-Perm., Cosmop.]

TABLE 16. Measurements of *Abrotocrinus unicus* in mm.

Measurements	Specimen														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dorsal cup height	6.7	8.6	7.6	7.3	7.5	7.0	7.9	7.1	7.0	8.0	7.1	7.0	9.0	8.1	6.5
Dorsal cup width	14.2	18.8	15.0	15.3	16.0	14.0	12.5	14.5			17.0		16.8		
Basals height	4.2	4.7	4.2	5.0	4.3	5.0	4.4	4.4	4.2	4.9	5.0	3.8	5.9	4.5	4.0
Radials height	3.1	4.0	3.4	3.0	4.1	3.8	3.8	3.9		3.0	3.3	4.0	4.9	3.7	3.8
Radials width	6.1	7.4	7.1	6.3	7.2	6.0	7.0	6.4	6.3	8.0	7.0	6.9	8.3	6.5	6.3
Arms length	56.3	58.4		66.5	80.0			39.0	68.0	59.0				78.0	
Stem diameter	5.4	5.5	4.6	4.8	5.0		5.9	4.8	5.2		5.0	4.9	5.8		60.0

1-7, UCWM 15824, 51824, 51825, 8914 A-D; 8, ISM 13155; 9, IGS 38195; 10-12, NYSM 11477, 11618, 11619; 13, YPM 6443; 14-15, WC 5, 32.

Pachylocrinus was originally erected for a group of inadunates characterized by a low bowl-shaped cup, concealed IBB, straight hinge lines with a gaping suture, short arms composed of wedge-shaped Brr, and a round or subpentagonal stem. The genus was later abandoned by WACHSMUTH & SPRINGER and its species were referred to *Woodocrinus*. Later SPRINGER (1911) revived the genus for species formerly placed in it and in *Scaphiocrinus*, which according to rules of nomenclature was invalid because its type was a junior synonym of a previously described species assigned to *Graphiocrinus*. WACHSMUTH & SPRINGER first classed *Scaphiocrinus* as a subgenus of *Poteriocrinus*, later raising it to the rank of genus; they characterized it especially by possession of a RA, and repeatedly branching arms, composed of more or less wedge-shaped Brr. Subsequently arm structure became emphasized so that almost any upper Paleozoic inadunate with 2 or 3 anals in the dorsal cup and arms branching dichotomously 2 or more times was referred to the genus. As a result, a large number of unrelated species were included in *Pachylocrinus* and *Abrotocrinus*, which was defined as a *Pachylocrinus* with a pentagonal stem. The latter genus, although containing a number of well-characterized species, has never been properly defined, and thus a redescription of it is included herein.

Many species that somewhat resemble *Pachylocrinus* have been indiscriminately assigned to the genus and review of such forms occurring at Crawfordsville indicates that most of them belong to other genera. *Scaphiocrinus granuliferus* MILLER & GURLEY is assigned to MEEK & WORTHEN's *Decadocrinus depressus*, *Scaphiocrinus disparilis* MILLER & GURLEY to *Scytalocrinus*, *Scaphiocrinus porrectus* MILLER to HALL's *Scytalocrinus robustus*, and *Scaphiocrinus coreyi* MEEK & WORTHEN to *Abrotocrinus*. Thus, as interpreted in this study, species of *Pachylocrinus* found at Crawfordsville include only *P. aequalis* and *P. gibsoni*. WHITE's *Scaphiocrinus gurleyi* is judged to be an immature form of *P. aequalis* and MILLER & GURLEY's *Scaphiocrinus manus*, originally described as occurring at Crawfordsville, actually is from Indian Creek.

***Pachylocrinus aequalis* (HALL, 1861) SPRINGER, 1911**

Plate 4, fig. 1, 3, 6, 10; text-fig. 33

Scaphiocrinus aequalis HALL, 1861a, p. 316; 1861b, p. 8; 1872 pl. 5, fig. 10.

Poteriocrinus (Scaphiocrinus) aequalis MEEK & WORTHEN, 1873, p. 494, pl. 15, fig. 6.

Pachylocrinus aequalis SPRINGER, 1911, p. 146; 1913, p. 222, fig. 1; 1926, p. 71, pl. 16, fig. 1; MOORE & PLUMMER, 1940, p. 137, text-fig. 19.

Poteriocrinus (Pachylocrinus) subaequalis WACHSMUTH & SPRINGER, 1879 (1880), p. 116 (p. 339) (Proposed as new name for *Scaphiocrinus aequalis* HALL, but invalid).

Scaphiocrinus gurleyi WHITE, 1878, p. 32; 1880, p. 162, pl. 40, fig. 3a (Final Report 1883); 1881, p. 509, pl. 7, fig. 8.

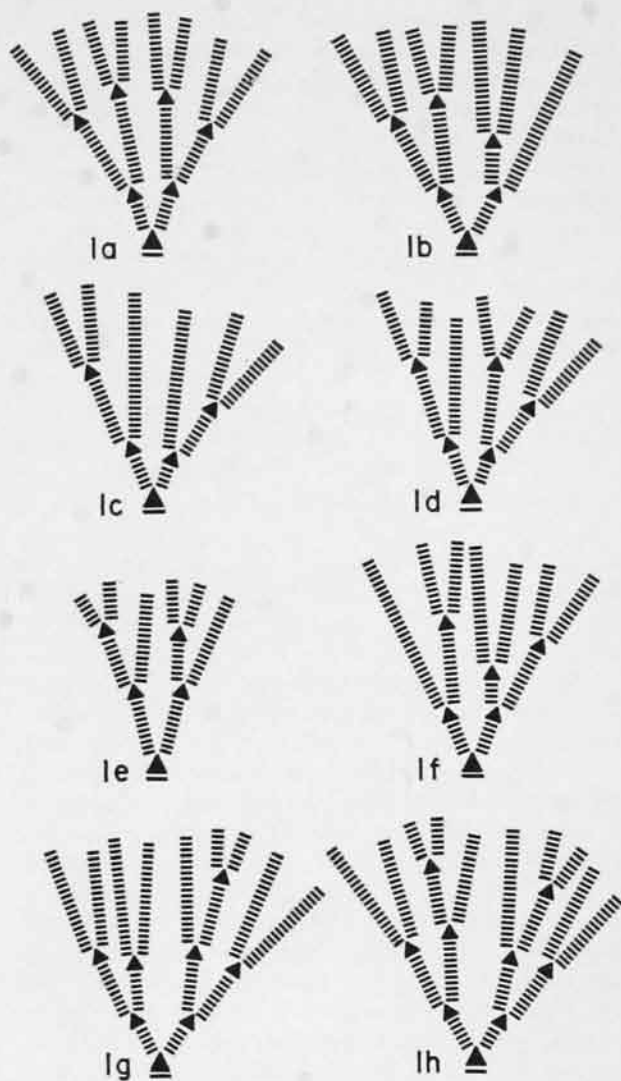


FIGURE 33. Observed variation of arm branching patterns on specimens of *Pachylocrinus aequalis*. Most distal brachials and variation of number of brachials in each series not included. Patterns shown in 1a-c are most common, but other modes of branching were observed on at least two different specimens. [EXPLANATION: See Fig. 31.]

Poteriocrinus (Scaphiocrinus) gurleyi, WACHSMUTH & SPRINGER, 1879 (1880), p. 114 (p. 337).

Pachylocrinus gurleyi SPRINGER, 1911, p. 147.

(non *Scaphiocrinus gibsoni* WHITE in SPRINGER, 1911, p. 147).

Diagnosis. Crown relatively elongate, commonly compact; dorsal cup low bowl-shaped, with broad basal concavity; small pitlike depressions at angles between B and R circlelets; BB inflated; RR small; arms rounded, commonly 4 or 6 bifurcations in each ray above IAxx, rarely 7 or 8, 2 IBrr in each ray, commonly protruding.

Description. Dorsal cup broad, lower portion with rounded outline, upper portion tending to flare outward,

plates appearing smooth but the surface of well-preserved specimens is seen to be coarsely granular. IBB small, subhorizontal or slightly downflaring; BB rather large, equal in size except CD basal, which is larger and more highly inflated; RR small, wider than high, slightly convex medially, sides curving inward, distal portion of interradial suture notched, R facet slightly crescentic, sloping gently outward, suture gaping. CD interray rather wide, anal X mostly below R circlet; RA commonly larger than anal X, supporting RT directly above. Anal sac poorly known, seemingly elongate, subcylindrical, not reaching tips of arms. Arms rounded, bifurcating first above IAxx on IIBrr₅₋₇, again at greater distance, very rarely on IVBrr; IBrr₁ short, quadrangular, distinctly convex, IBrr₂ axillary; pinnules long, slender. Stem round, lumen subpentagonal to nearly circular.

Remarks. *Pachylocrinus aequalis*, the type-species of the genus, is a well-characterized species that is represented by numerous specimens. Yet, judging from the number of specimens studied that were incorrectly labeled, considerable confusion still exists concerning the name that should be applied to it. In 1861, HALL described the species of *Scaphiocrinus aequalis*, but WACHSMUTH & SPRINGER changed the name to *Poteriocrinus (Pachylocrinus) subaequalis* because of supposed conflict with *Poteriocrinus aqualis* HALL, 1860. They considered HALL's most recent name to be a secondary homonym and cited his earlier name as *P. aequalis*. This incorrectly emended name was similarly listed by MILLER (1889, p. 273) and WELLER (1898, p. 540). However, the two names, as pointed out by SPRINGER (1911) are completely different; "aequalis" meaning equal, and "aqualis" pertaining to water. Thus, the conflict in names did not exist and HALL's *Scaphiocrinus aequalis* is the valid name for the species; WACHSMUTH & SPRINGER's *subaequalis* is a synonym of it. Further, HALL's name *Poteriocrinus aqualis* (now considered to belong to *Pelecocrinus*) remains valid even though he supposedly meant his trivial name to be derived from a word meaning "equal."

Scaphiocrinus gurleyi WHITE is judged to be a small, immature specimen of *Pachylocrinus aequalis* and is

herein placed in synonymy. It has a similar dorsal cup (but smaller) and rounded, long arms; however, it differs from most other specimens in having second bifurcations occurring on IIBrr₉₋₁₁. WHITE's *S. gibsoni*, considered by SPRINGER to be a synonym of *P. aequalis*, is judged by me to be a valid species, differing from the latter especially in having proportionately longer arms that are distinctly angular and provided with strongly wedge-shaped Brr that give arms a zigzag appearance.

Unlike many inadunate species, the arms of *Pachylocrinus aequalis* exhibit considerable variation in patterns of branching. These seemingly can occur on any ray and range from endotomous to uniform dichotomous branches. Rarely do more than 6 bifurcations take place in each ray above the IAxx; however, several atypical specimens were observed that branched 7 or 8 times. Considerable variation in the number of Brr in each series was observed and these are not included on Figure 33, which illustrates the common types of branches occurring in this species. Almost invariably IIBrr are much less numerous than IIIBrr, and IVBrr are more common than more proximal Brr.

Type. HALL's holotype could not be located, but a plaster cast of it (UCWM no. 15826) was available. SPRINGER's hypotype (1926, pl. 16, fig. 1) is USNM no. S-2587. WHITE's type of *Scaphiocrinus gurleyi* is USWM no. 6341.

Occurrence. Known only from Borden rocks at Crawfordsville. Judging from statements of previous authors and amount of material available for this study, it was probably one of the most abundant species at Crawfordsville.

Material. Nearly a hundred specimens of *P. aequalis* were available for study, of which 20 were selected for measurements. These included: UCWM no. 15826 (plaster cast of holotype); plaster cast of USNM no. S-2587; UCWM nos. 6341, 3215A,B, 51826A-F, 19199; NYSM nos. 11479, 11621; YPM nos. 2413.

Dimensions. Measurements of selected specimens of *Pachylocrinus aequalis* are shown on Table 17.

[*Pachylocrinus boonvillensis* (S. A. MILLER, 1891)
BASSLER & MOODEY, 1943]

BASSLER & MOODEY (1943, p. 94, 579) report this species from Crawfordsville, but this could not be confirmed in published descriptions of the species.

TABLE 17. Measurements of *Pachylocrinus aequalis* in mm.

Measurements	Specimen																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dorsal cup height	5.0	5.1	3.0	5.4	4.5	3.6	4.3	4.0	4.1	4.3	4.0	4.1	4.2	4.4	4.4	5.6	4.9	4.0	4.1	
Dorsal cup width	10.0	10.3	6.5	10.8	11.0	9.2	8.4	8.5	7.0	8.5	10.0	8.5	9.0	9.3	10.2		10.0	7.0		
Basals height	3.1	3.4	2.0	4.5	3.3	2.5	2.9	2.4	2.5	2.7	2.8	2.9	2.8	3.1	3.2	3.8	3.0	2.5	2.7	3.0
Basals width	3.0	3.4	1.9	4.2	3.6	2.8	3.5		2.7	2.8	3.0	3.2	2.8	3.0	3.2	3.9	3.6	2.8	3.2	3.1
Radials height	2.0	1.8	1.1		2.0	1.2	1.5		1.7	1.5	2.1		1.6	1.5	1.9	2.0	2.1	1.5	1.4	
Radials width	4.5	3.5	2.2		4.1	3.6	3.7	3.5	2.3	3.5	3.8	4.0	3.0	4.1	3.7	4.6	4.3	3.0	3.1	
Arms length	35.3	44.8	24.6	49.8	49.0	39.2	36.0	35.1	30.0	30.1	39.6	34.0	35.0	49.0	43.3	63.3	42.3	34.0	40.0	38.5
Stem diameter		3.4	2.5		2.8						2.7	3.3	3.2	3.2	3.6	3.8	4.1	2.6	3.1	2.6

1, UCWM 15826; 2, USNM S2587; 3-12 UCWM 6341, 3215 A, B, 51826 A-F, 19199; 13-14, NYSM 11479, 11621; 15-19, YPM 2413, 6453 A-D; 20, WC 49.

Pachylocrinus gibsoni (WHITE, 1878) SPRINGER, 1911

Plate 4, fig. 7, 11

Scaphiocrinus gibsoni WHITE, 1878, p. 31; 1880, p. 161, pl. 40, fig. 4a (Final Report 1883); 1881, p. 507, pl. 7, fig. 7; SPRINGER, 1911, p. 147 (as synonym of *Pachylocrinus aequalis*).

Poteriocrinus (Scaphiocrinus) gibsoni WACHSMUTH & SPRINGER, 1879 (1880), p. 114 (p. 337).

Diagnosis. Dorsal cup very small, bowl-shaped; BB and RA large, strongly inflated, RR and anal X convex; arms very long for size of cup, IBrr₂ axillary, Brr strongly wedge-shaped, giving a zigzag appearance to the arms, angular, with small but distinct longitudinal keel-like ridges on outside of Brr.

Description. Crown of medium size, arms 6 to 8 times as long as cup; dorsal cup broadly truncated. IBB small, completely concealed by stem; BB large, higher than RR, greatly inflated; RR small, uniformly convex, R facet straight to slightly crescentic, not strongly gaping; very small, deep pitlike depressions between plates of B and R circlets and CD interray. CD interray moderately wide; RA large, inflated with distinct pits at angles of surrounding plates; anal X only slightly convex, extending to top of IAxx. Anal sac unknown. Arms long, slender, commonly bifurcating endotomously in C and D rays, 3 to 5 bifurcations in each ray above IAxx, inner rami of division commonly remaining simple, second bifurcation occurs on IIBr₅₋₁₄, Axx only slightly larger than other Brr, plates distinctly angular. Stem round, wide for size of cup.

Remarks. The general form of *Pachylocrinus gibsoni* so closely resembles *P. aequalis* that SPRINGER considered it to be a synonym of the latter species. However, it differs in much greater proportionate length of arms, fewer bifurcations, and zigzag appearance of the arms that are coarsely granular and angular. Occurrence of four specimens with these diagnostic features indicates that the WHITE's holotype is not merely an abnormal specimen of *P. aequalis*. Also, comparison with equal-sized specimens of the latter species suggests that specimens belonging to *P. gibsoni* are not young or immature specimens of the former species.

Type. WHITE's holotype is USWM no. 6342. A plaster cast of USNM no. S-2598 labelled holotype was available, but it was so poorly constructed that comparison of it with specimen in Walker Museum could not be made. Seemingly, the specimen at U. S. National Museum is a cast of WHITE's holotype.

Occurrence. Known unquestionably from Borden rocks at Crawfordsville. In addition, BASSLER & MOODEY (1943, p. 93, 580) reported it as also occurring at Bono, Lawrence County, Indiana, but this was not confirmed.

Material. Besides the holotype, the following specimens were available for study: NYSM nos. 11478, 11620; YPM nos. 22754A, B.

Dimensions. Measurements of *Pachylocrinus gibsoni* are shown on Table 18.

TABLE 18. Measurements of *Pachylocrinus gibsoni* in mm.

Measurements	Specimen				
	1	2	3	4	5
Dorsal cup height	3.4	2.5			2.0
Dorsal cup width	7.6	5.0			4.1
Basals height	2.1	1.5			1.2
Basals width	2.2	1.4			1.1
Radials height	1.4	1.2			1.0
Radials width	2.7	2.1			1.4
Arms length	30.8	18.3	22.0	25.1	18.0
Stem diameter	2.5	1.3			1.4

1, UCWM 6342; 2-3, NYSM 11478, 11620; 4-5, YPM 22754 A, B.

Pachylocrinus manus (MILLER & GURLEY, 1890)

BASSLER & MOODEY, 1943

Plate 4, fig. 12

Scaphiocrinus manus MILLER & GURLEY, 1890, p. 645, pl. 4, fig. 13 (author's ed. p. 24).

Pachylocrinus manus BASSLER & MOODEY, 1943, p. 582.

Diagnosis. Dorsal cup small, low bowl-shaped, plates convex, slightly depressed at suture angles; arms moderately long for size of cup, rather stout, IBrr₁ axillary, much larger than RR, constricted, Brr quadrangular to slightly wedge-shaped, small, rounded nodes common along thickest portion of Brr, second bifurcation occurring on IIBrr₈₋₁₀.

Remarks. *Pachylocrinus manus*, commonly cited as occurring at Crawfordsville, is represented by a single known specimen from Indian Creek, Indiana. Its small cup, with slightly convex BB and RR, large IAxx and nodose arms easily distinguish it from Crawfordsville species.

Type. The holotype and only known specimen of this species is UCWM no. 6173.

Family POTERIOCRINITIDAE Austin & Austin, 1842
(Bassler, 1938)

[*nom. subst.* Bassler, 1938, p. 20 (pro Poteriocrinitidae Austin & Austin, 1843, p. 108=*nom. correct. pro Poteriocrinoidea*, p. 195)] [Dev.-Miss., Perm.]

During early years of investigations almost any Carboniferous and Permian dicyclic crinoid having 3 anals in the dorsal cup and pinnulate arms was assigned to the genus *Poteriocrinus* (or *Poteriocrinites*). Because many upper Paleozoic species possess these features a remarkable number of forms (over 300) were referred to the genus. With more recent ideas concerning those characters important for separating crinoids into natural divisions, and restudy of previously described forms, many species now are included in other genera. The number of recognized forms at present has dwindled to about 80, and undoubtedly these will also be reduced as the remaining species are re-examined.

The family Poteriocrinitidae remained broadly defined and contained most new genera that included forms

previously assigned to *Poteroicrinus*. MOORE & LAUDON (1943), as well as several earlier authors recognized the inadequate definition of this group of crinoids and proposed numerous families based on more restricted characters. Thus, as defined above, the three genera referred to this family are narrowly defined and represent a rather unspecialized group of inadunates.

Originally 15 species reported from Crawfordsville were referred to *Poteroicrinus* (or *-ites*), but now all except two, *Poteroicrinites nodobrachiatus* (HALL) and *P. verus* (MILLER & GURLEY), are assigned to other genera. Neither of the latter forms actually came from Crawfordsville. Thus, no species are now known from Crawfordsville that belong to *Poteroicrinites*, although numerous specimens still bear this name in various collections.

The monotypic genus, *Springericrinus* is commonly placed in the Poteroicrinidae but the nature of CD interray, which lacks three distinctive anals, suggests that it should be assigned elsewhere, possibly as the type of a new monotypic family.

Genus POTEROICRINITES J. S. Miller, 1821

[*Poteroicrinites nodobrachiatus* (HALL, 1861) BASSLER, 1938]

This species was founded on fragments of an unknown crinoid specimen and cannot be considered a valid species.

[*Poteroicrinites verus* (MILLER & GURLEY, 1890)
Bassler, 1938]

Specimens of this species were not found in the Crawfordsville beds as the authors stated in their original description, but are from Indian Creek; this is indicated by mode of preservation, type of matrix, and most important, the label accompanying the holotype.

Genus SPRINGERICRINUS Jaekel, 1918

[Miss. (Burl., Keokuk), Ind., Iowa]

Springericrinus JAEKEL, 1918, p. 62.

Diagnosis. Crown exceptionally large, dorsal cup plates folded into large, smooth ridges with deep triangular- or diamond-shaped depressions between them; ventral sac very large, broad below, tapering abruptly in distal portion to a point, composed of longitudinal rows of very short, wide plates with a median ridge that projects above transverse foldlike plates; arms long, stout, commonly 2 IBrr, more rarely 3 or 4; Brr short, slightly wedge-shaped.

Type-species. *Poteroicrinus magniventrus* SPRINGER, 1911, p. 155, pl. 5, fig. 1a, b, 2, 3, pl. 6, fig. 1-3.

Remarks. JAEKEL's abbreviated and generalized diagnosis of *Springericrinus* is as follows, "Arme schlank, mit

2-3 Brachialien, reich gegabelten Hauptästen, konischem Kelch mit stark gefalteten Platten, 3 Analien, 5 Infrabasalien. Analtubus sehr groß, aus Reihen sehr schmaler Plättchen aufgebaut, Stiel rund." The only characteristic he mentioned that sets this genus apart from many others with similar crowns is the strongly plicated margins of calyx plates. The presence of 3 anals is highly conjectural, for it is more likely that only one (or none) is characteristic of the genus. The exceptional size of this crinoid and features of the dorsal cup plates and anal sac readily distinguish *Springericrinus* from other inadunates.

Springericrinus magniventrus (SPRINGER, 1911)

JAEKEL, 1918

Plate 4, fig. 13, 17

Poteroicrinus magniventrus SPRINGER, 1911, p. 155, pl. 5, fig. 1a, b, 2, 3, pl. 6, fig. 1-3.

Springericrinus magniventrus JAEKEL, 1918, p. 62.

Diagnosis. Crown exceptionally large, possibly attaining a maximum length of 25 to 30 cm.; arms long, stout; IBrr commonly 2, rarely more, Brr short.

Description. Dorsal cup conical, large-sized, plates very thin, particularly where meeting adjacent ones, sutures corrugated. IBB about as wide as long, median distal portion forming lower part of deep triangular depression between BB, remainder of distal edges corrugated, inter-IBB sutures straight; BB large, surface of each marked by 2 or 3 strong folds extending from center to upper sloping margins, meeting corresponding structures of the lateral sloping faces of the RR, central fold extending proximally as wide, rounded, smooth elevated area, depressions serrate; RR much shorter than wide, 4 elevated smooth ridges radiating from distal portion, meeting corresponding raised areas from adjacent BB and RR corrugated extensions of smooth ridges, depressed portions serrate; R facets straight to oblique, sloping slightly outward. Anal plates not distinct, possibly entirely lacking, anal sac composed of longitudinal rows of short wide plates, with a median ridge that extends above the folds; each plate with a sharply elevated, rounded ridge and adjacent grooves; base of anterior and lateral tube composed of thick small ossicles. Arms long, stout, commonly 2 IBrr, more rarely 3 or 4, second bifurcation on IIBrr₁₂₋₁₅; Brr short, slightly wedge-shaped; pinnules short, stout, consisting of 5 to 10 pinnulars. Stem round, composed of alternating ossicles, lumen very large.

Remarks. The large size, distinctive anal sac and inter-cup plate depressions distinguish *Springericrinus magniventrus* from all other inadunates known. *Springericrinus doris* (HALL) from the upper Burlington Limestone at Burlington, Iowa, somewhat resembles this form in ornamentation and structure of anal sac, but the Crawfordsville species is much more robust, has more

exaggerated features on cup plates and more stout arms. Also it differs in having 2 or more IBrr and shorter Brr, and lacking 3 anals in the dorsal cup.

Type. All of the specimens figured by SPRINGER except Fig. 3, Pl. 5, and Fig. 2, 3, Pl. 6, which are presumably at the U. S. National Museum, are at Yale Peabody Museum. Only a single specimen (YPM no. 22752; SPRINGER's pl. 6, fig. 1) was available for study. According to the accompanying label this is the type (? Holotype).

Occurrence. Known only from the Borden rocks at Crawfordsville.

Dimensions. The following measurements were made on the only specimen available for study (YPM no. 22752): height of dorsal cup, 25.5 mm.; width of dorsal cup, 39.0 mm.; height of IB circle, 7.7 mm.; height of B circle, 13.5 mm.; height of R, 7.8 mm.; width of R, 16.8 mm.; width of arm facet, 6.7 mm.; width of stem, 10.0 mm. Because of the flattened nature of this specimen the measurements given are only approximate.

Family SCYTALOCRINIDAE Moore & Laudon, 1943

[M.Dev.-Penn.]

Previously, assignment of several Crawfordsville species has been referred to genera of this family that were rather broadly defined. Restricted interpretations of genera, as indicated on Table 19, has resulted in reallocation of several forms. Others were previously assigned to *Pachylocrinus*, but as interpreted by me this genus has a rather low truncate bowl-shaped dorsal cup and two or more branches in each ray.

Presence of 2 IBrr and arms that branch on IIBrr in *Hypselocrinus indianensis* differs from all other species assigned to this family, but other characters are similar. Difference in arm structure is judged merely to be an

advanced evolutionary trend within the genus. *Histocrinus* differs from most genera of scytalocrinids in possessing 2 IBrr in each ray; however, nature of cup, arms, and anal tube suggest assignment to this family.

Genus DECAODOCRINUS Wachsmuth & Springer, 1880

[Dev.-Penn., N.Am.; L.Carb., G.Brit.]

The erect, moderately long arms with stout pinnules and structure of the anal sac of *Decadocrinus* resemble *Histocrinus*. However, the latter differs in having a more conical dorsal cup, with IBB visible in side view, less wedge-shaped BB, and stouter pinnules. Two species of *Decadocrinus* have been reported from Crawfordsville, but considerable doubt exists if *D. tumidulus* occurred in the crinoid beds. Evidence indicates that it was erroneously reported from this locality by WACHSMUTH & SPRINGER (1897, p. 7) and BASSLER & MOODEY (1943, p. 93).

Decadocrinus depressus (MEEK & WORTHEN, 1870)

WACHSMUTH & SPRINGER, 1880

Plate 4, fig. 2, 4, 14

Scaphiocrinus depressus MEEK & WORTHEN, 1870, p. 27.

Poteriocrinus (Scaphiocrinus) depressus MEEK & WORTHEN, 1873, p. 492, pl. 14, fig. 6, 8.

Decadocrinus depressus WACHSMUTH & SPRINGER, 1879 (1880), p. 119 (p. 342).

Scaphiocrinus granuliferus MILLER & GURLEY, 1890, p. 367, pl. 10, fig. 3 (author's ed., p. 51). (Type labelled *S. granulifera*).

Diagnosis. Dorsal cup very small, broadly concave at

TABLE 19. *Characteristic Features of Scytalocrinid Genera Occurring at Crawfordsville*

Characters	<i>Decadocrinus</i>	<i>Histocrinus</i>	<i>Hypselocrinus</i>	<i>Scytalocrinus</i>
Crown/dorsal cup	Low bowl- or saucer-shaped, base flat or with slight concavity.	Crown compact, high cup subconical, plates smooth or with faint radial striations.	Crown very high, slender. Dorsal cup high, narrowly turbinate.	Crown high, slender. Cup commonly conical.
IBB	Not visible in side view.	Visible in side view.	Visible in side view.	Visible in side view.
CD interray	Anal X commonly large, extending above RR.	RA large, anal X same size as RR extending well above RR.	RA high, anal X well above RR.	3 anals in cup.
Anal Tube	Club-shaped, numerous rows of regularly arranged plates. Commonly as long as arms.	Subcylindrical, reflexed so that summit and anal openings are well down on ant. side.	Long, slender; 6 to 7 times height of cup.	Long, slender, tubelike, with elongate or subrounded pores.
Arms, shape/size	Isotomous, branching once.	Moderately stout, dichotomous, A ray may be atomous.	Very long, slender, A ray typically atomous.	Long, rather heavy spreading upwards; dichotomous.
IBrr	Commonly 1, rarely 2.	2 (except A ray).	1 (except in atomous A ray).	1
Brr	Strongly wedge-shaped with zigzag appearance.	Wedge-shaped.	Wedge-shaped.	Quadrangular or slightly wedge-shaped.
Pinnules	Moderately long, far apart.	Stout, typically short, stand out stiffly from arms.	Long, slender.	Long, slender.
Stem	Subpentagonal	Round	Round	Round

base; IBrr₁ commonly axillary, large, constricted medially; Brr long, bearing widely separated, long pinnules.

Description. Dorsal cup low bowl-shaped, nearly twice as wide as high, plates slightly to moderately granulose; IBB not visible in side view; BB about as high as wide, slightly convex, curving abruptly inward at base; RR much larger than BB, twice as wide as high, R facet straight to slightly gaping, extending nearly completely across plate. Anal X about size of RR but extending above them, all plates in proximal portion of CD interray slightly convex. Arms long, slender, rounded, Brr somewhat constricted, distal ends projecting slightly on alternate sides for support of pinnules; pinnules long, very slender, composed of long pinnulars. Stem narrow, round.

Remarks. MILLER & GURLEY's *Scaphiocrinus granuliferus* agrees in all essential features with *Decadocrinus depressus*, and is considered herein a synonym. The type of the latter species is not well preserved, and thus the arms appear slender and more spreading. BASSLER & MOODEY's assignment of MILLER & GURLEY's species to *Pachylocrinus* is incorrect because according to my interpretation of this genus the arms must bifurcate two or more times. *Decadocrinus tumidulus*, the other form of the genus that possibly occurred in the Crawfordsville beds, differs in having a much larger dorsal cup, more tumid BB, typically 2 IBrr in each ray, and longer, more robust arms.

Type. MEEK & WORTHEN's holotype is ISM no. 1811, now deposited in the Illinois Geological Survey Collection. Their figured specimen (pl. 14, fig. 6) is IDG no. X-1097. The holotype of *Scaphiocrinus granuliferus* MILLER & GURLEY is UCWM no. 62556.

Occurrence. This species has been reported from Borden rocks at Crawfordsville and Indian Creek.

Material. In addition to the above mentioned types only a single specimen (UCWM no. 8901) was available for study.

Dimensions. Measurements are shown in Table 20.

TABLE 20. *Measurements of Decadocrinus depressus in mm.*

Measurements	Specimens			
	1	2	3	4
Dorsal cup height	4.3	4.0	5.1	
Dorsal cup width	7.1	7.8	8.5	
Basal height	2.4	2.1	2.6	
Radial height	2.0	2.3	2.5	
Radial width	3.0	3.1	3.4	
Arm facet width	2.9	3.0	3.4	
Arms length	23.7	28.0	33.3	35.9
Stem diameter		1.6	1.9	

1, ISM 1811; 2-3, USWM 6255B, 8901; 4, IDG X1097.

Decadocrinus tumidulus (MILLER & GURLEY, 1894)
SPRINGER, 1900

Plate 4, fig. 15, 16

Cyathocrinus tumidulus MILLER & GURLEY, 1894, p. 31, pl. 3, fig. 7.

Decadocrinus tumidulus SPRINGER, 1900, p. 139, pl. 16, fig. 5, 6; 1926, p. 92, pl. 17, fig. 6.

Decadocrinus grandis WACHSMUTH & SPRINGER, 1897, p. 138, pl. 7, fig. 4, 5 (*errore pro D. tumidulus*).

Diagnosis. BB large, tumid; arms long, stout, bearing moderately long, somewhat stout pinnules, 2 IBrr in each ray.

Description. Dorsal cup large, low bowl-shaped, sutures strongly depressed, plates granular, base deeply concave. IBB small; BB large, strongly tumid; RR smaller than BB, only slightly convex, somewhat transversely angular in middle. Anal X smaller than RR, not extending above them. Anal sac long, stout, not extending to the tips of arms; pores numerous, commonly elongate; anal opening on upper half of tube. Arms long, rounded, composed of short, slightly wedge-shaped Brr; IBrr₂ axillary, except in A ray which is atomous. Stem round.

Remarks. Considerable doubt exists whether or not *Decadocrinus tumidulus* occurred in the beds at Crawfordsville. SPRINGER (1926, p. 92) indicated that it is known only from Indian Creek and near Canton, Indiana; however, previously (1897, pl. 7) he and WACHSMUTH stated that their illustrated specimens are from the Crawfordsville beds. No specimens referable to this species were found in the material available for study except the holotype, which was collected along Indian Creek, Indiana.

Type. MILLER & GURLEY's holotype is UCWM no. 6188. Specimens illustrated by SPRINGER are at U. S. National Museum.

Genus HISTOCRINUS Kirk, 1940

[Miss. (Burlington-Keokuk), Iowa-Ind.]

Two of the three known species of *Histocrinus* occurred in the Crawfordsville beds. *H. coreyi*, the type-species, was moderately abundant and 30 specimens were available for study. The incorrect trivial name *grandis* appears on most labels, but as discussed below, this name is invalid. Specimens of the small *H. graphicus* were rare and probably never formed an important element of the crinoid fauna.

Histocrinus is most likely to be confused with *Decadocrinus* because both have erect, stout arms with heavy comblike pinnules and similarly shaped anal sacs. However, *Decadocrinus* has a lower, more bowl-shaped dorsal cup, concealed IBB, more strongly developed wedge-shaped Brr, and commonly only a single IBrr in each ray. The single IBrr, more conical dorsal cup, and long slender arms readily distinguish *Scyatocrinus* from this genus.

Histocrinus coreyi (WORTHEN, 1875)

VAN SANT (n. comb.)

Plate 4, fig. 5, 8, 9; pl. 5, fig. 8, 9, 12

Poteroocrinus coreyi WORTHEN in WORTHEN & MEEK, 1875, p. 516, pl. 29, fig. 2, 3.*Poteroocrinus (Scytalocrinus) grandis* WACHSMUTH & SPRINGER, 1879 (1880), p. 118 (p. 341).*Histocrinus grandis* KIRK, 1940b, p. 328.? *Cyathocrinus dekadactylus* LYON & CASSEDAY, 1860, p. 73 (non *Poteroocrinites (Scaphiocrinus) coreyi* MEEK & WORTHEN, 1869, = *Pachyocrinus coreyi*; nec *Decadocrinus grandis* WACHSMUTH & SPRINGER, 1897, pl. 7, fig. 4, 5, = *Decadocrinus tumidulus*).

Diagnosis. Crown large; arms long, rounded, tapering slightly but uniformly in distal portion; *A* ray atomous; pinnules stout, moderately long, standing out stiffly from Brr.

Description. Dorsal cup bowl-shaped to subconical, plates smooth and thin, slightly convex, IBB small but well exposed in side view, extending about half their length above truncated base; BB moderately large, higher than wide; RR moderately small, R facet extending nearly full width of R, suture straight to slightly crescentic, but not gaping. *CD* interray broad, proximal plates large; anal *X* about same size as BB, slightly elongate, extending well above R cirlet; RA about as large as RR, resting subequally on *CD* and *BC* basals. Anal sac stout, subcylindrical, and opening on anterior lower half; proximal portion of posterior side consisting of series of 5 rather smooth, flat plates, higher plates becoming plicate; plates on expanded distal portion tumid and nodose. Arms moderately stout; IBrr₂ axillary, except in atomous *A* ray; Brr strongly wedge-shaped bearing stout, moderately long pinnules. Stem round.

Remarks. Considerable nomenclatural confusion exists concerning the correct name of this species. The name is important not only because of numerous errors on labelled specimens in various collections, but because this form is the type-species of the genus. *Poteroocrinites (Graphiocrinus; Scaphiocrinus) coreyi* MEEK & WORTHEN was originally proposed (1869) for a form now judged

to belong to *Abrotocrinus*. In 1875, WORTHEN proposed the name *Poteroocrinus coreyi* for an entirely different species. WACHSMUTH & SPRINGER (1879 [1880], p. 118) considered the latter to be a homonym and accordingly proposed the new name *P. (Scytalocrinus) grandis* for specimens assigned to this species. This name was most commonly recognized and KIRK (1940) cited it as type for his new genus *Histocrinus*; however, it is incorrect according to the rules because *Poteroocrinus coreyi* WORTHEN is not a homonym of *Poteroocrinites (Graphiocrinus; Scaphiocrinus) coreyi* MEEK & WORTHEN, and therefore must be retained as the name for the species.

Histocrinus coreyi differs from the other two known forms of the genus by its much larger size, more cone-shaped dorsal cup, and stout, rounded arms. *H. juvenis* (MEEK & WORTHEN) from the lower Burlington Limestone of Iowa also differs in having a dichotomous *A* ray and more strongly developed zigzag-shaped Brr that gives the arms a characteristic appearance. LYON & CASSEDAY'S *Cyathocrinus dekadactylus* probably is a junior synonym of *H. coreyi* but location of type or any specimens of it are not known and no illustrations accompanied the authors' rather generalized description.

Curatorial Problems. Besides the incorrect use of the trivial name *Poteroocrinus (Scytalocrinus) grandis* many specimens in the collection studied are improperly labelled *Decadocrinus grandis* or *D. coreyi*. Assignment of species to this genus are caused by (1) an illustration by WACHSMUTH & SPRINGER (1897) incorrectly labelled *D. grandis* instead of *D. tumidulus*, which superficially resembles this species, and (2) use of the name *D. grandis* by SPRINGER (1900, p. 144) rather than *Poteroocrinus coreyi*. Species assigned to *Decadocrinus* can be easily distinguished by their low bowl-shaped cups with flat or concave bases, concealed IBB, and commonly a single IBrr in each ray.

Type. Only one of WORTHEN'S original two illustrated specimens could be located (IDG no. X-1190), and it is herein selected as the neotype because the holotype is lost.

TABLE 21. Measurements of *Histocrinus coreyi* in mm.

Measurements	Specimens															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Dorsal cup height	10.9	13.4	11.3	8.0	11.2	14.4	11.4	10.0	8.6	10.2	12.1	7.2	9.0	6.1	11.4	11.0
Dorsal cup width	17.0			15.0		21.4		17.0	11.1	16.9			15.0	11.4	14.0	17.4
Infrabasal height	3.0	3.1	3.4		3.8	4.2	3.3	2.1	1.5	2.4			2.9		2.1	3.0
Basal height	6.0	5.1	6.4	6.3	6.4	8.0	5.4	5.3	5.2	6.0	6.0	4.0	5.3	4.2	5.6	7.8
Basal width	5.2			6.1	5.9		5.0	5.2	6.1	6.1	6.4			4.4		7.6
Radial height	4.5	4.4	4.4	3.6	3.9	4.5	3.2	3.2	3.8	3.6	3.5	3.1	4.1	2.0	3.0	4.1
Radial width	6.4	6.2	6.0	6.1		9.0		5.8	6.2	6.4	5.9	4.8	6.1	3.7	5.2	7.1
Anal sac height	44.3								38.0		51.4	37.0	41.4			
Arms length		73.5	58.3	81.0			60.3			96.5	74.0			39.0	70.0	78.3
Stem diameter	4.5	4.6	5.6	4.5	5.7	6.0		5.0	4.6	5.0		3.0	4.9	3.7	4.1	5.3

I, IDG X1190; 2-4, ISM 1820, 2074, 2408; 5-9, USWM 8911 A-E; 10-14, YPM 6445 A-E; 15-16, WC 3, 28.

Occurrence. This species was moderately abundant in the Crawfordsville beds and is also known from the Indian Creek beds.

Material. Thirty specimens of *Histocrinus coreyi* were available for study of which 16 were selected for measurements. These include: IDG no. X-1190 (neotype, labelled *Scytalocrinus grandis*); ISM (IGS) nos. 1820, 2074, 2408; UCWM nos. 8911A-E, YPM no. 6445A-E; WC nos. 3, 28.

Dimensions. Measurements of this species are shown on Table 21.

***Histocrinus graphicus* (MILLER & GURLEY, 1890)
KIRK, 1940**

Plate 5, fig. 2, 5

Scaphiocrinus graphicus MILLER & GURLEY, 1890, p. 366, pl. 10, fig. 4 (author's ed. p. 50).

Histocrinus graphicus KIRK, 1940b, p. 328.

Diagnosis. Dorsal cup small; IBrr₂ axillary, elongate, slightly constricted; arms small, length of Brr variable, upper truncated ends of each Br strongly projecting alternately on opposite sides.

Description. Dorsal cup subconical to bowl-shaped, plates slightly rounded, moderately granulose, with distinct sutures. IBB small, barely visible in side view; BB large, expanding slightly in distal portion; RR small, wider than high; R facet slightly crescentic, suture not gaping. CD interray wide, elongate; anal X small, extending to top of IBrr₁; RA large, slightly rounded, supporting RT directly above. Anal sac unknown; proximal portion consisting of 5 subequal plates diminishing in size distally. Arms widely spreading; Brr constricted, wedge-shaped; IBrr₁ small, nearly quadrangular, IBrr₂ elongate, axillary; pinnules moderately stout, short. Stem round.

Remarks. *Histocrinus graphicus* closely resembles *Decadocrinus depressus* in size of crown and appearance of arms, but it differs in having a more conical dorsal cup, exposed IBB, and shorter, stouter pinnules. It differs from *Scytalocrinus disparilis*, which has about equal size, in having a more bowl-shaped dorsal cup, 2 IBrr, shorter, more angular arms, and stout, short pinnules.

Type. The holotype of *Histocrinus graphicus* is UCWM no. 6170a.

Occurrence. Found only in Borden rocks at Crawfordsville.

Material. Besides the holotype, the only specimen available was NYSM no. 11480.

Dimensions. Measurements of specimens of this species are shown on Table 22.

TABLE 22. Measurements of *Histocrinus graphicus* in mm.

Measurements	Specimen	
	UCWM 6170A	NYSM 11480
Dorsal cup height	4.8	4.1
Dorsal cup width	6.4	6.8
Basal height	2.9	2.2
Radial height	1.9	2.1
Radial width	2.1	2.1
Arms length	26.0	23.0
Stem diameter	1.7	2.0

Genus HYPSELOCRINUS Kirk, 1940

[L.Miss., N.Am.]

KIRK originally assigned nine closely related species to *Hypselocrinus*, each characterized especially by a high, narrowly turbinate cup, one IBrr in each ray, except *A* ray, which may be atomous, and long, slender arms not typically bifurcating above the IBrr₁. The following year he proposed *Cosmetocrinus* (1941, p. 86), which according to his description has essentially the same diagnostic features as *Hypselocrinus*, except that the dorsal cup is subturbinate. In the latter were placed two Crawfordsville species, *Poteriocrinus crawfordsvillensis* MILLER & GURLEY and *P. indianensis* MEEK & WORTHEN. Comparison of these forms with others placed in the genus indicates that they differ in having a much larger and more cone-shaped cup, 2 IBrr₁ in each ray, absence of typical second bifurcations in the distal half of the arms, commonly a bifurcation on the lateral side of the *C* or *D* ray IBrr₂, and atomous arms in *A* ray. The difference in number of IBrr and mode of branching was explained by KIRK as "... abnormal, or an error in observation." As pointed out below (p.), both of these suppositions are entirely unfounded. His improper assignment was, in part, because he thought that MEEK & WORTHEN's figure and description were unrecognizable—which is not true. Obviously he had not seen the holotype because it agrees very closely with the original description and illustration.

KIRK's genera *Hypselocrinus* and *Cosmetocrinus* seem to contain two distinct groups of species that should be retained with slight revision of assigned generic characters and species. In my opinion *Cosmetocrinus* should be diagnosed as follows: dorsal cup low, cone- to bowl-shaped, IBB commonly small, not forming appreciable part of dorsal cup; one IBr in each ray; arms bifurcating a second time at about half their height. Described in this manner the following species would be included: *Poteriocrinus crineus* HALL, 1963; *Scaphiocrinus delicatus* MEEK & WORTHEN, 1869; *Scaphiocrinus elegantulus* WACHSMUTH & SPRINGER in MILLER, 1889; *Cosmetocrinus extentus* WRIGHT, 1951; *Cosmetocrinus meeki* KIRK, 1941 (new name for *Poteriocrinites* (*Scaphiocrinus*) *nanus* MEEK & WORTHEN, 1869); *Poteriocrinus richfieldensis* WORTHEN, 1882; questionably *Poteriocrinites* (*Scaphiocrinus*) *tethys* MEEK & WORTHEN, 1873.

Removal of *Poteriocrinus crawfordsvillensis* and *P. indianensis* is based on their more elongate dorsal cup, large outflaring IBB that form an appreciable part of cup, 1 or 2 IBrr in each ray, and atomous *A* rays. These forms resemble other species assigned to *Hypselocrinus* in size and shape of dorsal cup, arrangement of cup plates and long slender arms. However they differ in commonly having 1 or 2 IBrr in each ray and a second bifurcation on IBrr₂ of *C* or *D* ray, which are not interpreted as abnormal development or regeneration but as an advanced evolutionary character.

Hypselocrinus hoveyi (WORTHEN, 1875) KIRK, 1940

Plate 5, fig. 7, 16

Poteriocrinus hoveyi WORTHEN, 1875, p. 516, pl. 29, fig. 6.*Scytalocrinus hoveyi* SPRINGER, 1900, p. 145, pl. 16, fig. 8.*Hypselocrinus hoveyi* KIRK, 1940b, p. 326 (?non *Poteriocrinus* (*Scytalocrinus*) *robustus* (HALL) WACHSMUTH & SPRINGER, 1880, p. 118 (p. 343); = *Scytalocrinus robustus* HALL, 1861).**Diagnosis.** Arms long, slender, branching once; IBrr₁ axillary, greatly elongate, constricted slightly in middle.**Description.** Dorsal cup medium cone-shaped. IBB long, flaring outward slightly; BB very large, nearly same size as RR and elongate IBrr₂ combined; RR about as high as IBB, R facet straight, not widely gaping. Plates of CD interray unknown from specimens available for study and original description. Anal sac tall, composed of series of large plates that bear plications consisting of ridges and depressed linear areas containing pores. Arms very long and slender, Brr short, rounded, strongly wedge-shaped. Stem round, consisting of short subequal ossicles.**Remarks.** *Hypselocrinus hoveyi* most nearly resembles *H. calyculus* (HALL) from the Burlington Limestone of Iowa, but differs in having a more uniformly straight-sided large conical cup, larger IBB, relatively much larger BB and smaller pinnules. MEEK & WORTHEN'S *Poteriocrinites* (*Scaphocrinus*) *macroductylus* is considered a junior synonym of HALL'S species.**Type.** WORTHEN'S holotype could not be located and the specimens available for my study were preserved on slabs, and only two rays were exposed. Because of this no neotype is proposed.**Occurrence.** Reported from Borden rocks at Crawfordsville, Indian Creek, and Canton, Indiana.**Material.** Only two specimens of this species were available for study, KU no. 1821 and NYSM no. 11474. Both were preserved on slabs and only two rays were visible.**Dimensions.** Measurements of this species are shown on Table 23.TABLE 23. Measurements of *Hypselocrinus hoveyi* in mm.

Measurements	Specimen	
	KU 1821	NYSM 11474
Dorsal cup height	12.2	11.3
Dorsal cup width	14.0	12.4
Infrabasal height	4.8	3.8
Basal height		6.0
Radial height	4.1	3.6
Length of preserved arms	116.5	69.2

Hypselocrinus indianensis (MEEK & WORTHEN, 1865)

VAN SANT (n. comb.)

Plate 5, fig. 3, 7, 14

Poteriocrinus indianensis MEEK & WORTHEN, 1865b, p. 155; 1868a, p. 515, pl. 20, fig. 4, text-fig.*Poteriocrinus* (*Scytalocrinus*) *indianensis* WACHSMUTH & SPRINGER, 1879 (1880), p. 117 (p. 340).*Cosmetocrinus indianensis* KIRK, 1941, p. 88.*Poteriocrinus crawfordsvillensis* MILLER & GURLEY, 1890, p. 344, pl. 4, fig. 8 (author's ed. p. 23).*Cosmetocrinus crawfordsvillensis* KIRK, 1941, p. 87.**Diagnosis.** Dorsal cup elongate; IBB relatively long, A ray atomous; IBrr commonly 2, rarely one, relatively short.**Description.** Dorsal cup large cone-shaped, plates smooth to slightly granular, BB large, slightly longer than wide; RR only slightly wider than high, about half the size of the BB; R facet straight or slightly crescentic, extending full width of RR. Anal X large, elongate, extending to top of the D ray IAXx; RA high in cup, large, supporting nearly equal-sized RT. Anal sac tall, posterior side consisting of vertical series of large hexagonal plates in two rows, joined by smooth suture, sac plates on lateral sides connected with posterior series by plicate-appearing structures representing ridges and linear pore passages. Arms long, relatively slender; Brr slightly wedge-shaped in proximal portion, becoming strongly cuneate in more distal part, arms of C and D ray commonly bifurcating on IIBrr₂. Stem round, relatively wide.**Remarks.** MILLER & GURLEY'S *Poteriocrinus crawfordsvillensis* differs in no way from *P. indianensis* and is herein considered a synonym. The latter was figured so that the CD interray and portions of adjacent arms were visible and the type of *P. crawfordsvillensis* is preserved on a slab so that only A, B, and portion of C and E rays are visible. Specimens showing all rays indicate that these two previously described forms represent a single species. Confusion also resulted because MEEK & WORTHEN apparently did not recognize that their holotype has the IBB pushed against the BB, thus giving the dorsal cup a somewhat less elongate appearance.KIRK'S statement (1941, p. 87) that the arms of *Hypselocrinus indianensis* have an additional IBr in each ray and second bifurcation because of abnormal development or error in observation is untrue. Study of the holotype, as well as other specimens indicates that (1) no error was made by the original authors either in their description of number of plates or on their illustration, (2) abnormal growth resulting from regeneration of arms is not indicated by smaller size of parts of the arms, different shape and sizes of Brr or other features suggesting injury and subsequent regrowth. It seems clear that KIRK did not study the type of the species he discussed.*Hypselocrinus indianensis* can be distinguished from *H. hoveyi*, with which it occurred in the Crawfordsville beds by its more elongate dorsal cup, presence of 2 IBrr₂ in some rays, less elongate and medially constructed IBrr, and bifurcations on the IIBrr₂ of some rays.**Type.** The holotype of this species is ISM no. 10133 (IDG no. X-1089). MILLER & GURLEY'S type of *Poteriocrinus crawfordsvillensis* is UCWM no. 6398.**Occurrence.** Known only from Borden rocks at Crawfordsville. **Material.** In addition to types and several uncatalogued specimens that are poorly preserved the following specimens were available for study: UCWM no. 8899; UC no. 25032A.**Dimensions.** Measurements of this species are shown on Table 24.

TABLE 24. *Measurements of Hypselocrinus indianensis in mm.*

Measurements	Specimen			
	1	2	3	4
Dorsal cup height	11.5	15.1	16.2	12.7
Dorsal cup width	17.1	18.8	20.9	18.0
Infrabasal height	5.0	5.1	5.4	4.2
Basal height	7.4	8.2	7.8	6.6
Basal width	7.6	6.2		
Radial height	4.2	4.7	5.0	4.7
Radial width	6.0	6.1	6.2	
Arm facet width	5.1	5.8	6.0	
Stem diameter	6.7			6.2

1, ISM 10133; 2-3, UCWM 6398, 8899; 4, UC 25032A.

Genus SCYTALOCRINUS Wachsmuth & Springer, 1880

[Miss.-Penn., N.Am.; Carb., G.Brit., Belg., USSR]

The two species from the Crawfordsville beds referred to *Scytalocrinus* are very unequally distributed. *S. disparilis* is represented by two known specimens and *S. robustus* was one of the most common inadunate forms occurring in the beds. The latter has an uncommonly wide geographic range and is known from several Indiana localities, Hamilton, Illinois, and Burlington, Iowa. Reassignment of *Scaphiocrinus disparilis* MILLER & GURLEY from *Pachylocrinus* to this genus is based on nature and shape of dorsal cup and structure of the arms.

[*Scytalocrinus decadactylus* (MEEK & WORTHEN, 1860) BASSLER & MOODEY, 1943]

BASSLER & MOODEY (1943, p. 94) stated that this species is known from the Crawfordsville beds but known specimens from Indiana were found only near Canton.

Scytalocrinus disparilis (MILLER & GURLEY, 1890) VAN SANT (n. comb.)

Plate 5, fig. 4, 6

Scaphiocrinus disparilis MILLER & GURLEY, 1890, p. 367, pl. 9, fig. 1; pl. 10, fig. 2 (author's ed. p. 52).

Pachylocrinus disparilis BASSLER & MOODEY, 1943, p. 580.

Diagnosis. Crown small, IBB barely visible in side view, IBrr₁ axillary, extremely large, nearly as high as dorsal cup; Brr quadrangular to slightly wedge-shaped, proportionally large.

Description. Dorsal cup small, low bowl- to slightly cone-shaped, plates smooth to finely granulose, sutures distinct but not deeply impressed. IBB small, barely visible in side view; BB slightly larger than IBB, about as high as wide; RR moderately large, nearly twice the size of BB, rounded; R facet wide, extending nearly full width of plates, sutures gaping. CD interray and anal sac unknown. Arms moderately long for size of cup, rather heavy, rounded; IBrr₁ very large, slightly constricted medially; Brr longer than wide, rounded and smooth, commonly slightly constricted in middle; pinnules long, slender. Stem round, narrow.

EXPLANATION OF PLATE 3

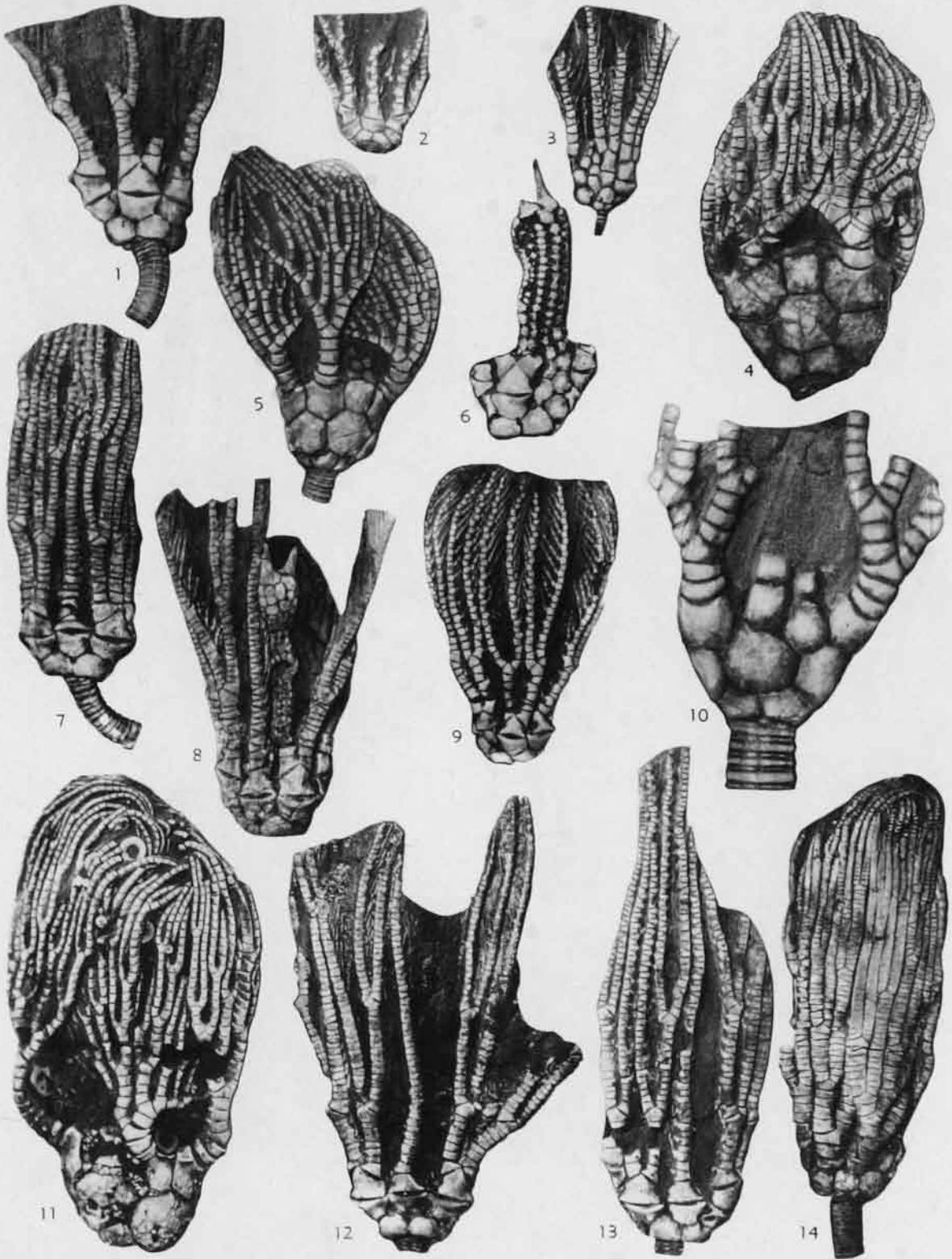
All figures are X1, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE

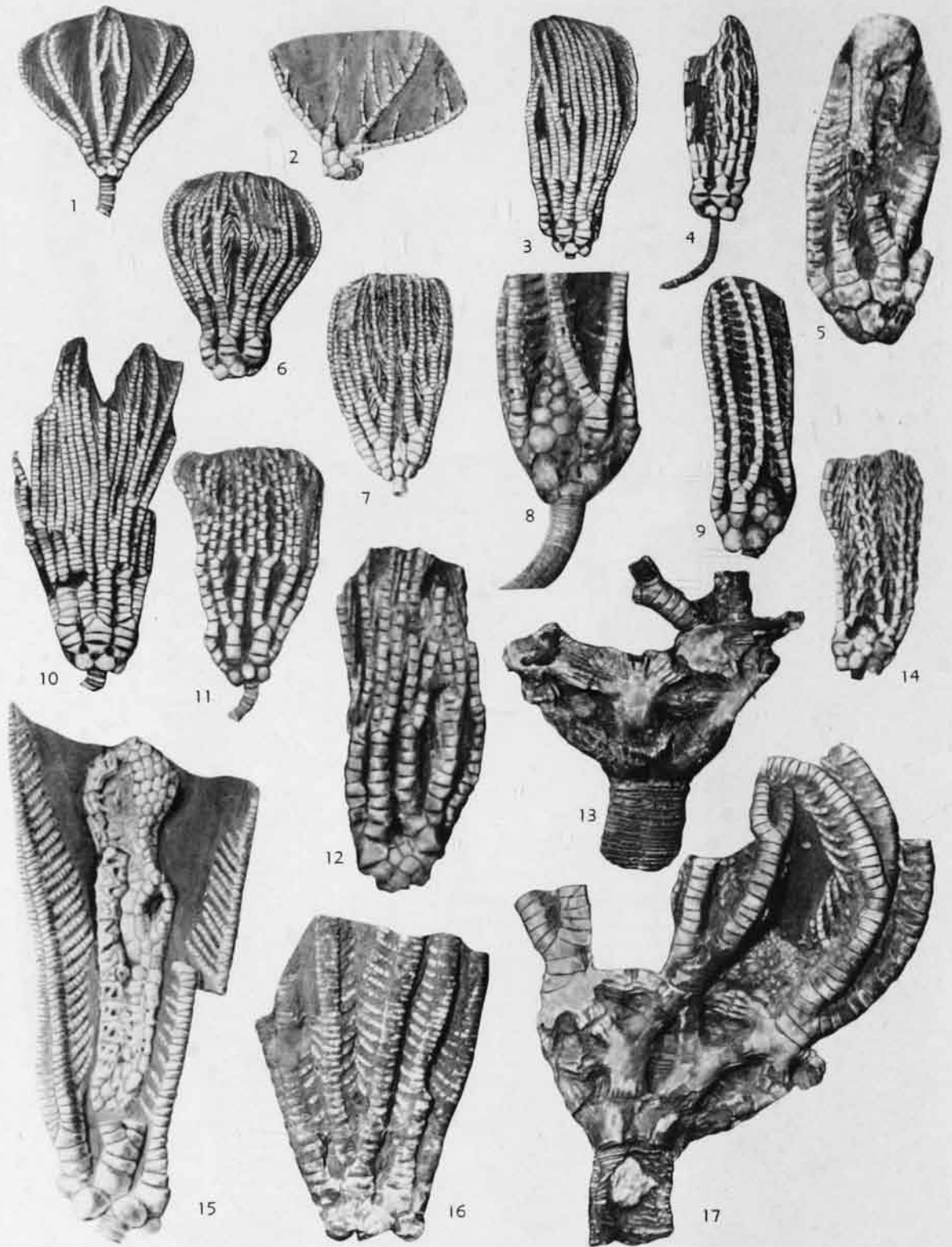
PAGE

- 1,6-8,12,13. *Abrotocrinus unicus* (HALL); 1, ?A ray view of crown with part of attached stem (NYSM 11470); 6, D ray view of dorsal cup and anal sac (UCWM 8914C); 7, A ray view of nearly complete crown and part of stem, specimen labeled "type A" (IDG ISM X739); 8, EA interray view of crown showing anal sac with anal opening at mid-height and spines above swollen summit (ISM 13155); 12, A ray view of crown showing slender unbranched arm in A ray (IGS 28P3); 13, A ray view of another crown (UCWM 8914B) 85
- 2,9. *Abrotocrinus coreyi* (MEEK & WORTHEN); 2, small incomplete crown from A ray side (ISM 8313); 9, A

- ray view of exceptionally well-preserved neotype (YPM 22754) 85
- 3. *Graphiocrinus mcadamsi* (MEEK & WORTHEN); C ray view of neotype (NYSM 11475) 83
- 4,5,10,11. *Cyathocrinites multibrachiatus* (LYON & CASSEDAY); 4, CD interray view of robust crown (YPM 6450A); 5, D ray view of specimen which well shows arm branching (ISM 10173); 10, CD view of large incomplete crown and proximal part of attached stem (UCWM 51831), X2; 11, E ray view of nearly complete crown (NYSM 11482) 80
- 14. *Cythrocrinus concinnus* (MEEK & WORTHEN); D ray view of fine crown, holotype (ISM IGS 1808) 83



VAN SANT & LANE—Crawfordsville Crinoids



VAN SANT & LANE—Crawfordsville Crinoids

Remarks. Transfer of this species from *Pachylocrinus* to *Scytalocrinus* is based on narrow definition of characters considered important in distinguishing certain inadunate families and genera. Presence of only a single bifurcation in each ray, long and rather heavy arms, and visible IBB in side view differ from all other pachylocrinids and suggests placement of this species in the scytalocrinids.

Scytalocrinus disparilis somewhat resembles small, young specimens of *S. robustus*, but it differs in having a lower, more bowl-shaped cup, less distinct IBB, and proportionally stouter arms. Also the IBrr₁ are much larger and distal Brr less tapering. *S. decadactylus* (MEEK & WORTHEN, 1860) differs in having a more conical cup, relatively much shorter IBrr, and larger, more compact arms, which are composed of short, wide, quadrangular Brr.

Type. MILLER & GURLEY's syntypes, which represent the only known specimens, are UCWM nos. 6170, 6171. The former is herein selected as the lectotype.

TABLE 25. Measurements of *Scytalocrinus disparilis* in mm.

Measurements	Specimen	
	UCWM 6170	UCWM 6171
Dorsal cup height	4.2	2.4
Dorsal cup width	6.8	4.7
Infrabasal height	0.9	0.5
Basal height	2.0	1.2
Basal width	2.1	1.1
Radial height	2.3	1.3
Radial width	3.4	2.1
Arms length	24.0	17.5
Stem diameter	1.2	1.3

Occurrence. Known only from rocks of Borden age at Crawfordsville.

Dimensions. Measurements of specimens of this species are shown on Table 25.

Scytalocrinus robustus (HALL, 1861)

BASSLER & MOODEY, 1943

Plate 5, fig. 10, 11, 13, 15

Scaphiocrinus robustus HALL, 1861a, p. 315; 1861b, p. 7; 1872, pl. 6, fig. 3-5.

Poteriocrinus (Scytalocrinus) robustus WACHSMUTH & SPRINGER, 1879 (1880), p. 118 (p. 341).

Scytalocrinus robustus BASSLER & MOODEY, 1943, p. 678.

Scaphiocrinus porrectus MILLER, 1892a, p. 652, pl. 7, fig. 2 (adv. publ. 1891, p. 42).

Pachylocrinus porrectus BASSLER & MOODEY, 1943, p. 583.

Diagnosis. Crown long, commonly compressed; dorsal cup low; IBrr₁ larger than RR; arms long, robust, commonly inflated in middle and tapering uniformly distally.

Description. Dorsal cup low bowl- to slightly cone-shaped, plates thick, slightly convex, smooth, with distinctly depressed sutures. IBB small, commonly barely visible in side view; BB of moderate size, wider than high; RR much wider than high, larger than BB, convex, R facet slightly gaping. CD interray moderately narrow; RA commonly larger than anal X, less elongate; RT small. Anal sac unknown. Arms long, robust, with uniformly rounded appearance; IBrr₁ axillary, commonly elongate, Brr quadrangular to slightly wedge-shaped; on some specimens middle portion of arms tend to thicken giving an elongate fusiform appearance; pinnules extremely long, slender. Stem round, composed of alternate thick and thin ossicles.

EXPLANATION OF PLATE 4

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE
1,3,6,10. <i>Pachylocrinus aequalis</i> (HALL); 1, ?A ray view of holotype of WHITE's <i>Scaphiocrinus gurleyi</i> (UCWM 6341); 3, AB view of crown (UCWM 51829); 6, A ray view of nearly complete crown (NYSM 11479A); 10, side of tall crown (UCWM 51826)	87
2,4,14. <i>Decadocrinus depressus</i> (MEEK & WORTHEN); 2, DE view of holotype (ISM 1811); 4, ?A ray view of MILLER & GURLEY's holotype of <i>Scaphiocrinus granuliferus</i> (UCWM 6255A); 14, CD view of well-preserved crown showing part of anal sac and typical arm structure (UCWM 8901)	91
5,8,9. <i>Histocrinus coreyi</i> (WORTHEN); 5, EA view of WORTHEN's holotype of <i>Poteriocrinites coreyi</i> (ISM 10169); 8, CD view of part of crown with attached stem (YPM 6445A); 9, D ray view of crown showing part of anal sac and arm characters (YPM 6445E)	93
7,11. <i>Pachylocrinus gibsoni</i> (WHITE); 7, CD view of crown figured by WHITE (1881, pl. 7, fig. 7); 11, ?EA view of crown (YPM 22754), $\times 2$	89
12. <i>Pachylocrinus manus</i> (MILLER & GURLEY), Indian Creek; CD view of holotype (UCWM 6173), $\times 2$	89
13,17. <i>Springericrinus magniventrus</i> (SPRINGER); 6a,b, CD and A views of specimen labeled as type (YPM 22752)	90
15,16. <i>Decadocrinus tumidulus</i> (MILLER & GURLEY); 15, B ray view of incomplete crown showing characters of anal sac with vent on anterior side above mid-height (specimen figured by WACHSMUTH & SPRINGER, 1897, pl. 7, fig. 4); 16, ?B ray view of specimen from Indian Creek (UCWM 6188)	92

Remarks. *Scaphiocrinus porrectus* MILLER differs in no way from typical representatives of *Scytalocrinus robustus* characterized by rather long tapering arms and is herein considered a synonym. Numerous Crawfordsville specimens labelled *S. decadactylus* are not conspecific with MEEK & WORTHEN's species from the Keokuk Limestone of Illinois, but they represent typical specimens of *S. robustus*. *S. decadactylus* differs in having a lower, more bowl-shaped dorsal cup with rather small IBB and BB, and very robust, closely spaced arms composed of short, subequal Brr. Also the IBrr₁ are smaller or only slightly larger than the RR.

In general appearance of crown, the Indian Creek species *Scytalocrinus validus* and *S. hamiltonensis* resemble *S. robustus*; however, they may be easily distinguished by having lower bowl-shaped cups, which are concave at the base, and short, very stout proximal arms. The nature of the IBB suggest that these forms should be assigned to *Decadocrinus*. *S. hamiltonensis* also differs in having pitlike depressions at the angles of the cup plates.

Type. The holotype of this species could not be located, but a plaster cast of it (UCWM no. 15826) was available for study. The holotype of *Scaphiocrinus porrectus* is UC no. 3402 and one of his paratypes is UC no. 3403.

Occurrence. *Scytalocrinus robustus* is one of the most widely distributed forms that occurred in the Crawfordsville beds. In addition to this locality, where, judging from amount of material available for study, it was abundant, it has been reported from Borden rocks at Indian Creek and near Canton, Indiana, Hamilton, Illinois and the so-called Burlington-Keokuk Transition Beds at Burlington, Iowa.

Material. The following 17 specimens were selected for measurements: UCWM no. 15825 (plaster cast of holotype, 3222A,B, 51823; UC nos. 3402, 3403 (holotype and paratype of *Scaphiocrinus porrectus*), 25031A-C, 25037B; ISM (IGS) no. 1819; IGS (ISM) nos. 1819, 28P2; NYSM nos. 11476, 11617; WC no. 46, 17. In addition 20 specimens, mostly uncatalogued, were available for study.

Dimensions. Measurements of selected specimens of this species are shown on Table 26.

Family ZEACRINITIDAE Kirk, 1942 (Moore & Laudon, 1943)
[Miss.-Perm.]

[nom. subst. Moore & Laudon, 1943, p. 58 (pro. Zeacrinidae Kirk, 1942, p. 382)]

Genus SAROCRINUS Kirk, 1942

[L.Miss., Iowa, Ind., Mo., ?Ohio]

By its shallow dorsal cup, presence of two IBrr in each ray except A ray, which has 3 or more, and isotomous arms *Sarocrinus* can be distinguished from *Zeacrinites* and *Woodocrinus*. Only a single specimen of this genus is known from the Crawfordsville beds.

Sarocrinus granilineus (MILLER & GURLEY, 1890)

KIRK, 1942

Plate 5, fig. 1

Poteriocrinus granilineus MILLER & GURLEY, 1890, p. 22, pl. 4, fig. 7 (private publ.); p. 365, pl. 4, fig. 7.

Sarocrinus granilineus KIRK, 1942, p. 382.

? *Sarocrinus* sp. KIRK, 1942, pl. 58, fig. 10.

Diagnosis. Surface of plates coarsely granular; Brr subangular, with keel-like ridge extending down middle of aboral (outside) surface.

Description. Dorsal cup low, basin-shaped. Lower part of BB within deep basal concavity, small; RR wide and extremely short. Anal X rather large, supported by CD basal and RA, extending nearly to top of IBrr₁ of D ray; RA elongate. Arms short, stout and in lateral contact throughout their length, except in CD interray; Brr broad, quadangular to slightly wedge-shaped; 2 IBrr in each ray, except in A, which has 3 or more, IIBrr₆ axillary, all rays except left rami of D ray unbranched above IIAxx; pinnules unknown. Stem small, appearing somewhat pentagonal.

Remarks. *Sarocrinus granilineus* most nearly resembles *S. nitidus* KIRK, 1942, type for the genus, from Indian Creek, Indiana; however, the latter differs in having smoothly rounded Brr and much finer granulose ornamentation. The specimen figured by KIRK (pl. 58, fig. 10) from Crawfordsville and labelled *Sarocrinus* sp. possibly is a large specimen of *S. granilineus*, but his illustration does not show details or ornamentation and thus, comparisons cannot be made. However, the IIBrr of the right division of the C ray show traces of the keel-like ridges characteristic of this species.

TABLE 26. Measurements of *Scytalocrinus robustus* in mm.

Measurements	Specimen																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dorsal cup height	8.3	7.7	4.9	4.8	7.8	6.7	6.3	8.2	7.8	6.9	8.7	8.0	5.1	5.3	5.8	7.3	7.4
Dorsal cup width	14.0			8.8	17.0	11.0		16.3			13.2	13.9					11.2
Infrabasal height	2.9	2.8	1.2	0.6		2.0		2.6	2.8		2.0			1.2	1.5	2.2	2.3
Basal height	3.7	4.0	3.0	2.5	5.4	3.5	3.6	4.5	4.0		4.6		3.5	2.4	3.2		3.8
Radial height	4.0		2.6	2.3	3.6	3.2	3.1	3.2	3.1	2.3	3.2	3.2	2.6	2.6		3.5	3.0
Radial width	7.2	5.4	4.1	3.8	7.0	5.0	5.0	6.0	5.9	3.8	5.0	4.8	4.4	4.0	4.2	4.5	5.0
Arms length		65.4	40.0	32.2	68.0		52.7	70.0	66.2	53.5	51.2	60.2	43.3	27.0	50.0	50.9	58.2
Stem diameter			2.3	2.2	3.0	3.0	2.6	3.3			2.9		2.5	1.9	3.1	2.8	

1-4, USWM 15825, 3222 A, B, 15823; 5-10, UC 3402, 3403, 25031 A-C, 25037B; 11, ISM 1819; 12-13, IGS 1819, 28P2; 14-15, NYSM 11476, 11617; 16-17, WC 46, 17.

Type. MILLER & GURLEY's holotype and the only specimen available for study is UCWM no. 6260.

Occurrence. Known only from Borden rocks at Crawfordsville, where it was rare.

Dimensions. The following measurements in mm. were made on the holotype: length of B cirlet above stem impression 2.1 mm.; height of R, 1.9 mm.; width of R, 5.0 mm.; height of IB_{r1}, 2.8 mm.; width of IB_{r1}, 5.4 mm.; length of arms, 28.6 mm.

[*Sarocrinus plenus* KIRK, 1942]

BASSLER & MOODEY (1943, p. 94) stated that specimens of this species were reported from Crawfordsville; however, these authors (p. 670) and KIRK (1942, p. 386) report that the single known specimen was found near Canton, Indiana (USNM S-4407).

Family UNCERTAIN

Genus CORYTHOCRINUS Kirk, 1946

[L. Miss., Iowa, Ind.]

No specimens referable to this genus were present in the material available for my study. Since KIRK's article is readily accessible, the species reported from Crawfordsville are merely diagnosed.

Corythocrinus fragilis KIRK, 1946

Corythocrinus fragilis KIRK, 1946, p. 270, pl. 40, fig. 5-7.

Diagnosis. Dorsal cup large, plates relatively thin, with distinct small nodes that coalesce; IBB relatively high, forming about a third of the cup height; BB larger than RR; anal X supported by CD and BC basals, extending well above R cirlet; arms stout, IB_{r2} lenticular, enclosed by IB_{r1} and IA_x, 11 to 13 IB_r; stem large, ossicles low, with large lumen.

Remarks. *Corythocrinus fragilis* differs from *C. gracilis*, with which it was associated in the Crawfordsville beds, by its large size, relatively stout arms with enclosed IB_r, and relatively much shorter Brr.

Type. KIRK's holotype is USNM no. S-4486.

Occurrence. Known only from Borden rocks at Indian Creek and Crawfordsville. Seemingly, specimens were very rare at both localities.

Corythocrinus gracilis KIRK, 1946

Corythocrinus gracilis KIRK, 1946, p. 271, pl. 40, fig. 4.

Diagnosis. Dorsal cup low, narrow cone-shaped, plates covered with distinct but small nodes; IBB relatively low; RR much larger than BB; anal X about same size as RR, extending above them; arms slender, IB_r long, relatively narrow, one division above IA_x relatively high; stem circular.

Remarks. In general size and appearance *Corythocrinus gracilis* more closely resembles *C. insculptus* KIRK, 1946, from the Indian Creek beds than the other form of the genus occurring at Crawfordsville. However, it dif-

fers in lacking distinct pits at the angles of the cup plates and presence of a second bifurcation occurring in upper portion of arms.

Type. The holotype is USNM no. S-4440.

Occurrence. This species was proposed from a single specimen that occurred in the Crawfordsville crinoid beds.

Genus GONIOCRINUS Miller & Gurley, 1890

[L. Miss., Iowa, Ind.]

Goniocrinus was, until recently, referred to the family Ottawacrinidae MOORE & LAUDON; however, re-examination of the genus *Ottawacrinus* by MOORE (1962b, p. 35) indicated that this genus differs from other forms referred to the family in many significant characters, and thus these genera should be reassigned. However, this is not within the scope of my study.

Goniocrinus harrisi (MILLER, 1880)

VAN SANT (n. comb.)

Cyathocrinus harrisi MILLER, 1880, p. 255, pl. 15, fig. 2.

Goniocrinus? harrisi MILLER & GURLEY, 1890, p. 352.

No specimens of *Goniocrinus harrisi* were available for study. According to MILLER's description this species is unquestionably referable to the genus, and can be distinguished from other known species by presence of 4 IB_r in each ray, narrower R facet, absence of RA, and spool-shaped Brr. MILLER's description is as follows:

Body, cup-shaped, about twice as wide as high, and ornamented by depressions at the corners of the plates, and rounded or sub-angular ridges between them. Subradials [BB], hexagonal, except the one on the azygos side [CD interray] which is heptagonal, and a little longer than the others. First radials [RR], wider than high, pentagonal or sub-pentagonal, with longer side uppermost. The anterior arms bifurcate on the fourth free arm plate [IB_{r4}]. The facet for the reception of each radial is only about half the breadth of the upper face of the radial. The plates are slightly constricted and rounded in the middle, and much flanged at the upper part, presenting an appearance somewhat similar to a series of small, short spools, piled one upon another, and gradually diminishing in size. Our specimens do not show the second bifurcations of these arms. There is a short, strong pinnule springing from each side of each arm plate above the first bifurcation. Below this, I suppose the pinnules were only long enough to protect the arm furrows, as none of them are visible [pinnules referred to are actually small unbranched armllets].

The first azygos plate is subquadrangular in outline, and about half the size of the adjoining first radials. It supports a series of plates which are flanged at the upper part, and gradually diminish in size while preserving their length, and also by contracting in the middle become more nearly spool-shaped. Six of these, above the azygos plate, are shown in our specimen.

The column is pentagonal, and for about an inch below the head every fourth plate bears 5 side arms cirri . . .

A lengthy section on the stem, which is full of suppositions, follows but not included herein.

Type. MILLER's holotype, the only known specimen, is USNM no. 40895.

Occurrence. Known only from Borden beds at Crawfordsville.

FLEXIBLE CRINOIDS

Only a single family of flexible crinoids occur in the Crawfordsville crinoid beds although previous authors erroneously reported that the sagenocrinitids also were described from the beds. Four species, representing three genera, are described below.

Subclass FLEXIBILIA Zittel, 1879

Order SAGENOCRINIDA Springer, 1913

[Sil.-Perm.]

Family SAGENOCRINITIDAE Roemer, 1854 (Bassler, 1938)

[M.Sil.-L.Miss.]

[nom. subst. Bassler, 1938, p. 23 (pro Sagenocrinitidae Roemer, 1854, p. 228)]

Genus FORBESIOCRINUS de Koninck & le Hon, 1854

[L.Carb., N.Am., G.Brit., Eu.]

[*Forbesiocrinus multibrachiatus* LYON & CASSEDAY, 1859]

Specimens reported from Crawfordsville (BASSLER & MOODEY, 1943, p. 93, 479) were actually found in the Indian Creek beds. The nomenclatural confusion that has developed between this species and *Taxocrinus colletti* is described further in the discussion of the latter species.

[*Forbesiocrinus wortheni* HALL, 1858]

BASSLER & MOODEY (1943, p. 93, 480) reported that specimens of this species were found in the Crawfordsville beds but this could not be confirmed in published accounts of the species.

Order TAXOCRINIDA Springer, 1913

[M.Ord.-M.Penn.]

Family TAXOCRINIDAE Angelin, 1878

[Ord.-Penn.]

Although flexible crinoids are much less abundant at Crawfordsville than other subclasses, some forms are well represented. *Taxocrinus colletti* is one of the most abundant species, and no other form of Flexibilia is known anywhere in such abundance. Species of *Onychocrinus* are much less abundant, but comprise a conspicuous aspect of the crinoid fauna. The only known species of *Parichthyocrinus* in these beds, however, is represented by two rather poorly preserved specimens, and as indicated below, may not be properly assigned to this family.

The morphology, classification, and description of crinoids referred to the Flexibilia have been discussed in detail by SPRINGER (1920) in his comprehensive monograph on this group of crinoids. Because no significant additional information could be added to his descriptions,

the crinoid species belonging to this subclass found at Crawfordsville are merely diagnosed, and selected specimens were measured and illustrated. Discussion of these crinoids has been included in my study only for the sake of completeness and because numerous problems of a curatorial nature were encountered. Also, as previously discussed, the mode of union between plates of this group of crinoids is distinctive and provides excellent examples of types of articulations developed between nonrigid crinoid ossicles.

Genus ONYCHOCRINUS Lyon & Casseday, 1860

[Miss.(Burl.-M.Chester), N.Am., G.Brit.]

Species of *Onychocrinus* represent a highly specialized group that were rather short-lived, being restricted to Lower Carboniferous rocks. Division of ray into 2 free rami on which are borne small, subordinate arms (armlets) distinguish it from all other flexible crinoids. The anal structure closely resembles *Taxocrinus* and because immature specimens of these genera are very similar, it is probable that *Onychocrinus* developed directly from a *Taxocrinus*-like ancestor.

Species assigned to *Onychocrinus* can be divided into two well-defined groups, and because of their abundance, good preservation, and characteristic features, the Crawfordsville forms can be considered typical specimens of these groups. The first, represented by *O. exculptus*, includes forms with numerous, well-developed iBrr and tendency to extend arms horizontally. This group began in Burlington time with *O. diversus* MEEK & WORTHEN (1866) and culminated with *O. ulrichi* MILLER & GURLEY (1890) and *O. exculptus* in the Keokuk. The group typified by *O. ramulosus*, on the other hand, is characterized by few iBrr, rami longer than rays below, and tendency for arms to remain in a vertical position after death. It began with *O. ramulosus* in Keokuk rocks and continued into Middle Chesteran, and is represented in North America by *O. magnus* WORTHEN (1875) (St. Louis Limestone; Illinois, Missouri), *O. distensis* WORTHEN (1882) (Renault Formation; Illinois, Alabama), and *O. pulaskiensis* MILLER & GURLEY (1895) (Okaw Formation; Kentucky, Alabama, Illinois).

Onychocrinus exculptus LYON & CASSEDAY, 1860

Plate 7, fig. 10; text-fig. 14; 34-2

Onychocrinus exculptus LYON & CASSEDAY, 1860, p. 78. MEEK & WORTHEN, 1873, p. 498, pl. 14, fig. 4.

Onychocrinus exculptus WACHSMUTH & SPRINGER, 1879 (1880) p. 55; WHITE, 1882, p. 365, pl. 40, fig. 1; QUENSTEDT, 1885, p. 947, pl. 75, fig. 27; SPRINGER, 1920, p. 430, pl. 67, fig. 6, pl. 69, fig. 1-9, pl. 70, fig. 1-7, pl. 71, fig. 1-2.

Forbesiocrinus? norwoodi MEEK & WORTHEN, 1860, p. 389.

Onychocrinus norwoodi MEEK & WORTHEN, 1866, p. 245, pl. 17, fig. 3.

Forbesiocrinus monroensis MEEK & WORTHEN, 1861, p. 130.

Onychocrinus monroensis MEEK & WORTHEN, 1866, p. 244, pl. 17, fig. 7; KEYES, 1894, p. 224, pl. 30, fig. 2.

Diagnosis. Crown moderately elongate; rami strongly diverging, longer than main rays below bifurcation, slender and gradually tapering distally, armllets delicate, clusters numerous, commonly 13 to 15 in mature specimens; 4 IBrr; iBrr numerous, well-developed.

Remarks. This species, type for the genus, occurs with *Onychocrinus ramulosus* in Crawfordsville beds, and can be easily distinguished from it by numerous iBrr and numerous delicate clusters of armllets (Fig. 34,2). *O. exculptus* somewhat resembles *O. diversus* from the upper Burlington Limestone at Burlington, Iowa, and *O. ulrichi* from rocks of Keokuk age at Indian Creek in general size and tendency for arms to be extended horizontally. However, *O. diversus* differs in having short rami with 3 to 5 stout clusters of armllets and a small anal tube. *O. ulrichi* differs in having rami of intermediate length with short and robust rays with 6 to 9 clusters of armllets, and a large anal tube (pl. 6, fig. 6, 8).

Most of LYON & CASSEDAY's species were not illustrated because, according to SPRINGER (1920, p. 431), these authors did not have the financial means to do so. However, LYON prepared drawings of all his types in hopes of someday publishing them. The Civil War brought an end to LYON's active life as a paleontologist and he was unable to continue work because of wounds suffered during the war and general failing health. His collection of crinoids, including his original drawings and unfinished manuscripts, were subsequently purchased by SPRINGER, who eventually published many of LYON's illustrations. His type for this species was published in SPRINGER's monograph on flexible crinoids (pl. 69, fig. 1, 2).

MEEK & WORTHEN's *Forbesiocrinus? norwoodi* from Keokuk Limestone at Nauvoo, Illinois, and their *F. monroensis* from equivalent beds in Monroe County, Illinois, represent mature and young forms, respectively, of this species. They stated (1866, p. 245) that *O. norwoodi* was probably the same species as *O. exculptus*, and that the main differences between it and *O. monroensis* were its larger size and presence of 2 non-diverging rays. This last feature is judged to be merely individual variation, and thus both of MEEK & WORTHEN's species are considered synonyms herein.

TABLE 27. Measurements of *Onychocrinus exculptus* in mm.

Measurements	Specimens			
	1	2	3	4
Crown height	105.5	73.0	85.9	53.0
Crown width	75.0	53.4	57.5	39.0
Ratio of height to width	1.4	1.4	1.5	1.4
Basal cirlet width	20.8	18.7	21.5	17.5
Stem diameter	13.2	9.0		7.7
Ray to arm bifurcation length	38.7	35.0	40.0	23.2
Ramus above fork length	65.8		46.2	

1-3, UCWM 8929 A, B, C; 4, ISM 1822.

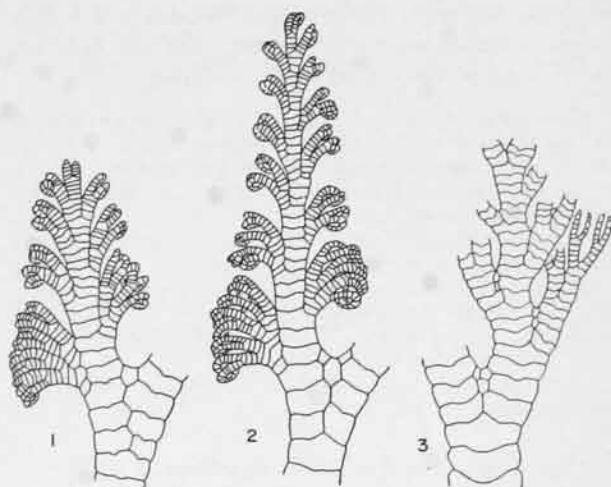


FIGURE 34. Modes of arm branching in three species of *Onychocrinus*.—1. *O. ulrichi* from Indian Creek.—2. *O. exculptus* from Crawfordsville beds.—3. *O. ramulosus* from Crawfordsville beds. Note number and arrangement of arm clusters. Approx. X $\frac{3}{4}$. (After Springer, 1920.)

Curatorial Problems. Several Crawfordsville specimens were labelled *O. ulrichi*; however, they represented typical specimens of *O. exculptus*.

Type. LYON & CASSEDAY's type is now in the Springer Collection (USNM).

Occurrence. Known from the Edwardsville Formation at Crawfordsville, and Keokuk Limestone at Keokuk, Iowa, Nauvoo and Monroe County, Illinois.

Material. Only 5 specimens of this species were available for study: UCWM nos. 8929A-D; ISM (IGS) no. 1822.

Dimensions. Measurements on the specimens available for study are given on Table 27.

Onychocrinus ramulosus (LYON & CASSEDAY, 1859) WACHSMUTH & SPRINGER, 1880

Plate 6, fig. 2, 7, 9; text-fig. 34-3

Forbesiocrinus ramulosus LYON & CASSEDAY, 1859, p. 237. QUENSTEDT, 1885, p. 947, pl. 75, fig. 26.

Onychocrinus ramulosus WACHSMUTH & SPRINGER, 1879 (1880), p. 55; WHITE, 1882, p. 366, pl. 39, fig. 2, 3; WACHSMUTH & SPRINGER, 1897, p. 75, table B, fig. 7; SPRINGER, 1920, p. 433, pl. 72, fig. 1-12.

Diagnosis. Crown greatly elongated, large; 3 short IBrr, broadly rounded; rami very long, tapering distally, commonly 2 or 3 times as long as ray below first bifurcation; armllets long, united to main rami by several Brr or small iBrr, and branching alternately, not forming clusters; stem of moderate diameter, long.

Remarks. This species can be distinguished from all other forms in the *O. ramulosus* group, such as *O. magnus*, *O. distensus*, *O. wrighti*, by development of small iBrr in the distal axial regions of the arms, and by strong well-developed rami (Fig. 34,3). LYON & CASSEDAY when

proposing the genus *Onychocrinus* did not include this form in it because they misinterpreted the anal structure and thought it was similar to *Forbesiocrinus*.

Curatorial Problems. Crawfordsville specimens mislabelled *Taxocrinus ramulosus* (HALL) were found in several collections. HALL's species from the upper Burlington Limestone in Iowa is a typical *Taxocrinus*, and is easily distinguished by its isotomous arms and low, broadly subtrifurcate crown.

Occurrence. Known from Borden rocks at Crawfordsville, and Hardin and Barren Counties, Kentucky.

Material. Specimens available for study and suitable for measurements included the following: plaster cast of holotype, USNM no. S-1874; WC no. X; UCWM no. 8930, 51834A-F; IGS (ISM) 1819, 28P5; NYSM no. 11484; UC no. 25010.

Dimensions. Measurements made on specimens available for study are shown on Table 28.

[*Onychocrinus ulrichi* MILLER & GURLEY, 1890]

BASSLER & MOODEY (1943, p. 94, 579) reported that specimens of this species were found at Crawfordsville but this is a mistake. Several Crawfordsville specimens of *Onychocrinus exculptus* available for study were mislabelled *O. ulrichi*.

Genus PARICHTHYOCRINUS Springer, 1902

[Miss. (Burl., Keokuk), Iowa, Ill., Ind.]

This genus is represented at Crawfordsville by the atypical species, *Parichthyocrinus crawfordsvillensis*. As discussed below (p. 103) Crawfordsville specimens labelled *Forbesiocrinus* or *Taxocrinus meekei* by early paleontologists and collectors are actually specimens of *T. colletti* and not *P. meekei* (HALL).

The arm structure of *Parichthyocrinus* does not resemble other taxocrinids; however, structure of anal tube so closely resembles *Taxocrinus* that only logical placement of genus is in the taxocrinids.

Parichthyocrinus crawfordsvillensis is unlike other species in the genus and is assigned herein with question. The two known specimens are crushed, and thus nature of certain structures is impossible to determine. It is possible that these specimens should be referred to the sagenocrinitid genus *Forbesiocrinus*. Specimens assigned to this genus are not known from Crawfordsville; how-

ever, *F. multibrachiatus* and *F. wortheni* occurred in the Indian Creek crinoid beds.

Parichthyocrinus? crawfordsvillensis (MILLER & GURLEY, 1894) SPRINGER, 1920

Taxocrinus crawfordsvillensis MILLER & GURLEY, 1894 (1893), p. 49, pl. 4, fig. 3.

Parichthyocrinus crawfordsvillensis SPRINGER, 1920, p. 416, pl. 53, fig. 5, 6.

Diagnosis. Crown large; anal tube bordered by strong, irregular, well-developed plates; arms broad and flat, rays not prominent; iBrr numerous.

Remarks. This species is represented by two known specimens, both of which are from Crawfordsville. They are greatly compressed laterally and therefore details of the anal area cannot be studied in detail. *Parichthyocrinus crawfordsvillensis* differs from typical species of this genus in the development of strong, irregular plates bordering the anal tube and numerous iBrr in several rays. Because of distorted nature of the CD interray, true structure of the anal tube and its relationship with CD basal is impossible to judge. It is possible that this species should be referred to *Forbesiocrinus multibrachiatus*, which it closely resembles in all other features of taxonomic importance. This species is one of several sagenocrinitids that develop a series of median plates in the anal area resembling the anal tube of taxocrinids; however, the tube does not fit into a socket on the CD basal as in taxocrinids, but is in sutural contact with adjoining plates. These species also have a tendency to develop numerous iBrr.

Type. MILLER & GURLEY's holotype is UCWM no. 6257, and the other known specimen is in the Springer Collection (USNM).

Occurrence. Known only from the Borden beds at Crawfordsville.

Material. The holotype was the only specimen available for study.

Dimensions. General measurements of the holotype, after amount of distortion was interpolated, are as follows: length of crown, 50 mm.; width of crown, 40 mm.; base, 11 mm.

Genus TAXOCRINUS Phillips, 1843

[M.Dev.-L.Carb., N.Am., G.Brit., Belg.]

TABLE 28. Measurements of *Onychocrinus ramulosus* in mm.

Measurements	Specimens											
	1	2	3	4	5	6	7	8	9	10	11	12
Crown height	100.5	82.7	87.0	62.3	66.7	70.0	55.5	75.5	85.5	62.1	80.0	107.0
Crown width	54.5	40.7	43.0	29.0	34.2	30.0		36.0	37.8	34.0	40.0	63.0
Basal cirlet width	17.0	18.2	14.0	10.0	11.5	10.0		11.0	12.5	12.0	15.5	
Stem diameter	13.0	12.6	10.6	8.0	8.0	11.2	7.5	8.0	10.5	10.0	11.0	14.7
Ray to arm												
bifurcation length	23.8	26.5	23.0	19.0	19.0	20.5	15.0	16.0	20.0	20.7	26.7	27.0
Ramus above fork length	62.3	54.0	60.0	37.5	46.0	51.8	40.0	42.5	62.8	40.0	53.6	74.4

1, WC X; 2-8, USWM 8930, 51834 A-F; 9-10, IGS 1806, 28P5; 11, NYSM 11484; 12, UC 25010.

Keokuk forms of *Taxocrinus* are most easily confused with typical sagenocrinitids of the *Forbesiocrinus multibrachiatus*-type. The latter have a tendency to arrange anal plates in a vertical series and because a line of weakness commonly develops causing the left margin of plates to become detached, the remaining anals resemble an anal tube. If the anal area is well preserved little confusion results because the relation between the CD basal and anal tube is entirely different in the two genera. Further, *Forbesiocrinus* is characterized by profuse development of iBrr, which gradually diminish in size distally. Some specimens of *Parichthyocrinus* superficially resemble several species of *Taxocrinus*; however, the former can be distinguished by having its rays abutting above the iBrr, instead of having rays wholly separated by iBrr or peristome.

Taxocrinus colletti WHITE, 1880

Plate 6, fig. 1, 3-5, 10; text-fig. 12-5, 6, 7, 8; 13

Taxocrinus multibrachiatus var. *colletti* WHITE, 1880, p. 506, pl. 6, fig. 3 (2nd ed. 1881, p. 138).

Taxocrinus colletti MILLER & GURLEY, 1894 (1893), p. 49; SPRINGER, 1920, p. 398, pl. 21, fig. 4, pl. 55, fig. 11, pl. 56, fig. 1-11, pl. 57, fig. 1-10.

Forbesiocrinus meeki QUENSTEDT, 1885, p. 946, pl. 75, fig. 24, 25 (non HALL, 1858, p. 631, pl. 17, fig. 3 = *Parichthyocrinus meeki*).

Taxocrinus splendens MILLER & GURLEY, 1896a, p. 59, pl. 5, fig. 3, 4.

Diagnosis. Crown large, slightly elongate, widest at IIIA_x; well-developed iBrr; arms long, regularly tapering, 3 to 4 iBrr; stem large, composed of extremely thin ossicles near theca, contracting abruptly, columnals becoming more elongate and denticulate distally.

Remarks. *Taxocrinus colletti* most closely resembles *T. praestans* SPRINGER (1920) from Indian Creek and Canton, Indiana, but can be distinguished by its smaller size, narrower and shallower Brr, and the abrupt contraction of the stem. It differs also in commonly having 3 iBrr rather than 4. *T. ungula* MILLER & GURLEY (1896), also found at Indian Creek, differs from these forms by its short, broad crown, evenly tapering stem, and clawlike rays that bifurcate by wide angles above III Brr. MILLER & GURLEY's *T. splendens* was founded on a typical specimen of *T. colletti* and differs in no significant characters of taxonomic importance.

WHITE (1889, p. 506) proposed *Taxocrinus multibrachiatus* var. *colletti* for a specimen that closely resembled LYON & CASSEDAY's *Forbesiocrinus multibrachiatus*, but he judged the latter species to belong to *Taxocrinus*. He stated that his form differed from typical representatives in having 4 iBrr in each ray; however, as shown by his published illustration, he completely misinterpreted the true nature of the iBrr. The iBrr₃ are axillaries as indicated by their angular distal sutures. Further, the

abruptly contracting stem indicates that WHITE's specimen is a typical representative of this species and not a variety of LYON & CASSEDAY's *Forbesiocrinus multiramus*, which is an entirely different form.

Curatorial Problems. Many specimens of this species have been mislabelled in collections available for my study. Considerable confusion in the proper name for this species has caused a great many names to be incorrectly applied to typical specimens of *Taxocrinus colletti*. In summary, specimens were commonly labelled *Taxocrinus* or *Forbesiocrinus multibrachiatus* and *Taxocrinus* or *Forbesiocrinus meeki*. The name *F. multibrachiatus* was proposed by LYON & CASSEDAY (1859, p. 235) for specimens said to be from Montgomery County, Indiana, and Hardin County, Tennessee. Because no illustrations were published, and the description agreed in a general way with specimens being found at Crawfordsville, collectors and some paleontologists thought that these specimens were typical examples of LYON & CASSEDAY's species. WACHSMUTH first recognized that the CD interray had the structure of a typical taxocrinid and labelled specimens *Taxocrinus multibrachiatus*. Many of these specimens subsequently went to the Museum of Comparative Zoology (Harvard) and other museums in this country. Later SPRINGER obtained LYON & CASSEDAY's types and other specimens of *F. multibrachiatus* collected from Indian Creek and these unquestionably lack a taxocrinid-like anal tube, and thus are entirely different from specimens labelled by WACHSMUTH from Crawfordsville. Therefore, LYON & CASSEDAY's species is a valid one, but it was not found in Crawfordsville beds and those labelled by WACHSMUTH from Crawfordsville are typical specimens of *T. colletti*.

Considerable confusion was also caused by early collectors (e.g., HOVEY, COREY, BASSETT, BRADLEY, BRAUN) because they commonly mislabelled specimens *Forbesiocrinus meeki* following a description of HALL's species from the Keokuk Limestone of Iowa and Illinois. This species was founded on an imperfect specimen without arms and subsequently has been shown by SPRINGER (1920, p. 414) to belong to *Parichthyocrinus*. Most specimens sent to Europe by BRAUN, HOVEY and others, as well as many in American museums still bear HALL's original name. Further confusion resulted from QUENSTEDT's (1885, pl. 75, fig. 24, 25) illustration of a typical specimen of *Taxocrinus colletti*, which he called *F. meeki* and an illustration by ZITTEL (1895, p. 138, fig. 275), which was labelled *T. meeki*.

Type. The whereabouts of WHITE's holotype, formerly in John Collett's Collection (University of Indiana), could not be located and it is presumed to be lost. Specimen UCWM no. 26479 is designated herein as the neotype.

Material. Twenty-five specimens of this species were available for study, of which nine were selected for measurements (UCWM no. 8935, 26479, 7054, 51835A-C; IGS (ISM) no. 1810A; NYSM no. E338; MILLER & GURLEY's holotype of *Taxocrinus splendens*, UCWM no. 6460.

TABLE 29. Measurements of *Taxocrinus colletti* in mm.

Measurements	Specimens								
	1	2	3	4	5	6	7	8	9
Crown height	51.0	52.9	51.8	44.3	47.3	54.0	63.9	54.3	43.8
Crown width	39.5	48.6	45.2	36.2	46.4	52.9	57.6	43.6	36.6
Stem diameter									
below cup	7.9	8.3	10.0	7.7		8.2			7.2
Stem diameter									
below enlargement	5.7	5.5	6.6			5.4			5.5
Stem enlargement									
length	17.5	10.0	15.8			11.5			14.7

1-7, UCWM 6460, 8935, 51835 A-C, 26479, 7054; 8, IGS 1810A; 9, NYSM E338.

Occurrence. This species is abundant in the Borden beds at Crawfordsville, but rare at Indian Creek.

Dimensions. Because most of the specimens measured were distorted, measurements of height and width of theca must be considered only approximate. Measurements of available specimens are shown on Table 29.

[*Taxocrinus ungula* MILLER & GURLEY, 1896]

BASSLER & MOODEY (1943, p. 94) reported that specimens of this species have been found at Crawfordsville, but all known specimens occurred in the Indian Creek beds.

CAMERATE CRINOIDS

Six camerate families, represented by 13 genera are described from the material available for study. The monocyclic camerates are most abundant, but they are very unevenly distributed in abundance of individual specimens. A total of 17 species are described of which only one is a dicyclic form.

Subclass CAMERATA Wachsmuth & Springer, 1885

Order DIPLOBATHRIDA Moore & Laudon, 1943

[Ord.-Miss.]

Family RHODOCRINITIDAE Roemer, 1854 (Bassler, 1938)

[Ord.-Miss.]

[*nom. subst.* BASSLER, 1938, p. 25 (*pro* Rhodocrinitidae ROEMER, 1854, p. 228)]

Genus GILBERTSOCRINUS Phillips, 1836

[Dev.-L. Carb., N. Am.-G. Brit.-Belg.]

The peculiar tubular appendages that arise from the margin of the tegmen are unknown in other crinoids (Fig. 35). Surprisingly, little has been published on these structures, except in specific descriptions, and their function still remains a matter of conjecture. The general structure of the appendages is similar in all known species, but differences in details exist. Ten appendages extend horizontally from the margin of the tegmen, but commonly within a short distance they become pendent and in some species extend below the base of the theca. Each extension is pierced by a central canal, which seems to connect with unknown structures only at their proximal end. No pores or openings are known to occur at the distal tip or along the length of the appendages. Surrounding the canals is either a single series of cylindrical ossicles, or more commonly 3 rows of ossicles so arranged that 2 rows of plates are ventral and the third is dorsal. As previously described, the apposing surfaces, at least on specimens of *G. tuberosus*, have well-develop-

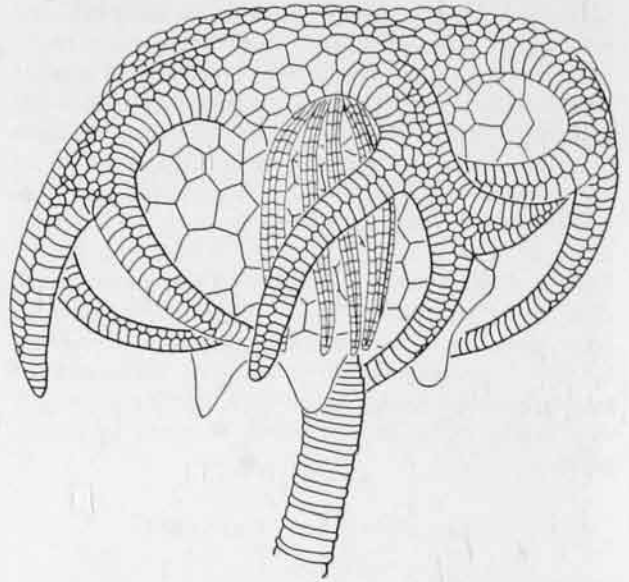


FIGURE 35. Diagrammatic sketch of the crown of *Gilbertsocrinus tuberosus* showing relationships of large tubular appendages, small delicate arms, and large spinelike infrabasals, X1.2 (after Wachsmuth & Springer, 1897; Ubaghs, 1953).

ed articulations. Therefore this type of union undoubtedly allowed limited flexibility. In most of the American forms the appendages meet near the tegmen and 5 compound appendages form, but the individual central canals remain separate. In this portion, the number of plates is doubled so that 4 ventral plates and 2 dorsal ossicles surround the compound tubes. In European species and several American forms the appendages remain single and all 10 individual extensions are in contact with the tegmen. According to WACHSMUTH & SPRINGER (1897, p. 235) the hollow tubes connect with subtegminal grooves within the theca and in species with compound canals the individuals of each pair connect with different ambulacra.

Little is known about the origin and function of these structures; UBAGHS (1953, p. 702) has suggested that they may have resulted from hypertrophy of proximal pinules. Their position and construction suggest modification of tegminal plates, however. Previous postulates have considered them to be modification for housing structures important in body functions (e.g., respiration), but as discussed below, they probably served several different functions and may not have been connected to the ambulacral system at all.

Early workers (e.g., HALL, PHILLIPS, LYON, CASSEDAY) thought that the appendages are arms, although some authors recognized the true arms and suggested that the appendages probably did not function as normal arms. BILLINGS (1858, p. 25, 26) thought that they were nothing

more than tegminal spines. Later ROFE (1865, p. 247) in commenting on Billings' interpretation stated that the articulated nature of the plates and the canal "... forbid the idea of their being spines." He concluded that they represented true arms and that the openings below the arms (Amb openings) were "ovarian openings." MEEK & WORTHEN (1866, p. 220) were the first to indicate that the "pseudo-ambulacral appendages" were not arms and "... differ essentially from all other appendages of the body in any known crinoid. . . ." They also illustrated the true relationship of the arms and theca. GRENFELL (1875, p. 483) suggested that the canals were "efferent tubes," and functioned in carrying off water used in respiration, which he thought was performed in other groups by the anal tube. However, he did not satisfactorily explain how the water escaped from the tubes. WACHSMUTH & SPRINGER seem to be the only investigators who tried to trace the canals into the tegmen. They stated (1897, p. 238) that the canals connect with the subtegminal grooves on the inner floor of the tegmen, and thus the structures were important in respiration, functioning in manner similar to the respiratory pores of *Batocrinus* and the spiracles of blastoids.

Disarticulation of several specimens by me of *Gilbertocrinus tuberosus* failed to confirm WACHSMUTH & SPRINGER's supposition. If the canals served to house nerve tissue and extensions of the coelom, comparable to the lumen of the stem, its connection with appropriate subtegminal structures would also be necessary. Thus, although a respiratory function is possible, a function similar to the lumen of the stem cannot be discounted. Although paired central canals do not appear in stems, as they do in these structures, when one considers that this condition developed late phylogenetically in *Gilbertocrinus*, it is conceivable that the canals would have eventually coalesced.

Examination of specimens and published illustrations indicate that the appendages served several important functions not previously suggested. The mode of union between ossicles provided limited mobility and thus a somewhat prehensile capacity similar to that of cirri resulted. Therefore, they may have served for aiding in support. The delicate arms found in all species of this genus were protected by the appendages and as in some other forms with pendent arms the extensions were longer than the arms and bowed out in such a manner that the arms when in relaxed position were close to the theca.

An interesting secondary modification in this genus was the formation of greatly elongate nodes or spinelike projections on the RR. These served to limit the lateral movement of the distal portion of the tubular appendages when brought close to the theca.

Another function of the appendages may have been to help circulation of water surrounding the theca. A

whipping action was not possible but undoubtedly back-and-forth movement of the appendages would serve to sweep gentle currents of food containing sea water toward the arms.

In summary, although the respiratory function of the tubular appendages cannot be entirely discounted, it is reasonable to suppose that they also served directly or indirectly: (1) to help support or anchor the theca, (2) protect the delicate arms, and (3) to agitate the water near the arms.

[*Gilbertocrinus dispansus* WACHSMUTH & SPRINGER, 1897]

BASSLER & MOODEY (1943, p. 93, 486) report that this species was cited as occurring in the Crawfordsville beds, but it is known only from the Indian Creek locality.

Gilbertocrinus tuberosus (LYON & CASSEDAY, 1859)
WACHSMUTH & SPRINGER, 1897

Plate 8, fig. 10, 12, 14, 15; text-fig. 20-5; 35

Goniasteroidocrinus tuberosus LYON & CASSEDAY, 1859, p. 233; MILLER, 1892b, p. 661, pl. 9, fig. 11 (adv. pub. 1891, p. 51).

Gilbertocrinus (Goniasteroidocrinus) tuberosus MEEK & WORTHEN, 1866, p. 220, fig. A-D.

Ollacrinus tuberosus WACHSMUTH & SPRINGER, 1881, p. 219.

Gilbertocrinus tuberosus WACHSMUTH & SPRINGER, 1897, p. 239, pl. 15, fig. 1a,b; pl. 16, fig. 1-6; pl. 17, fig. 6; EHRENBERG, 1929, p. 30, fig. 20.

non *Trematocrinus robustus* HALL, 1860, p. 77, text-fig.

Diagnosis. Theca large, slightly higher than wide, tegmen somewhat expanded beyond dorsal cup; cup plates tumid, with moderately large, subcentral tapering node on each plate; RR large, with elongate node directed obliquely downward; 4 to 6 biserial arms to each arm opening.

Description. Dorsal cup subcylindrical, base concave. IBB small, almost completely covered by stem; BB forming sides of concavity; RR large, nodes commonly approaching spinelike projections, shape of nodes varying from slightly elongate to spinelike protuberances affecting the entire plate; IRR large, commonly with single sharp nodes; iBrr medium-sized, nodose, arranged in 3 longitudinal rows, 9 to 15 plates in each row. IB_{r2} axillary, large; 2 IIBrrF, smaller than IBrr, IIBr₃ considerably smaller than proximal BrrF, IIBr₂₋₃ separated by 2 to 4 iIBrr causing arm openings of each ray to be rather widely separated; 6 to 8 free arms in each ray, pendent, slender; pinnules long. Tegmen low, almost flat, plates highly convex, deep interrarial depressions formed by somewhat smaller plates; interrarial appendages 5, long, branching by wide angles once or twice, tapering in distal portion, 2 ventral plates arranged longitudinally and a single dorsal plate around each individual hollow tube; anus opens directly through tegmen in CD interray de-

pression, which is commonly larger and composed of more numerous small plates than other depressions. Stem round, rather stout and long; columnals short, alternating narrow and slightly wider ossicles.

Remarks. WACHSMUTH & SPRINGER's *Gilbertocrinus dispansus* from Indian Creek bears close resemblance to *G. tuberosus*, but differs in having a smaller, somewhat lower theca, less numerous arms, and proportionally larger interradial appendages. Also, it has convex rather than tumid plates that except for RR are not node-bearing.

HALL's *Trematocrinus robustus* from the Keokuk Limestone of Iowa was considered a junior synonym of *G. tuberosus* by WACHSMUTH & SPRINGER; however, examination of a plaster cast of HALL's holotype (UCWM no. 15822) indicates that it differs in several important respects. The dorsal cup is proportionally longer and composed of highly convex plates that are not node-bearing. Further, the RR have only a slight elongate downward projecting node. The arms and interradial appendages are unknown in HALL's species.

The nearly flat tegmen of *G. tuberosus*, as well as other species of this genus, was well suited for attachment of *Platyceras*. Almost half of the specimens available for study have this coprophagous gastropod attached. On some (e.g., pl. 8, fig. 12, 14) the molluscan shell is larger than the crinoid theca, and it is difficult to visualize how the crinoid was able to support so large a "fellow traveler."

Type. LYON & CASSEDAY's holotype is USNM no. S-2. IDG no. X-1185 (ISM no. 12897) is labelled type, but penciled note states, "is not type F. (rank) S. (pringer) 1904." MEEK & WORTHEN's hypotype is IDG no. X-829 (ISM no. 10132) and WACHSMUTH & SPRINGER's hypotypes are USNM no. S-1a-c.

Occurrence. This species is restricted to rocks of Borden age east of the Illinois Basin. In addition to Crawfordsville, it has been reported from near Canton, Washington County, and Indian Creek, Montgomery County, Indiana, and from the Ft. Payne Chert at Clear Creek, Hardin County, Kentucky. Judging from number of specimens in various collections it was one of the most abundant camerate species in Crawfordsville crinoid beds.

Material. Approximately 50 specimens of *G. tuberosus* were available for my study of which 8 were selected for measurements.

Dimensions. Measurements of selected specimens available for study are shown on Table 30.

TABLE 30. *Measurements of Gilbertocrinus tuberosus in mm.*

Measurements	Specimens							
	1	2	3	4	5	6	7	8
Dorsal cup height	24.3		16.0	22.9	26.2	25.7	29.0	
Dorsal cup width				25.0				
Radial length (including node)	8.4		4.0	9.0	6.0	8.3	6.2	
Stem diameter	7.0		4.2	5.0	6.5	4.5		
Appendages length	51.8	39.0						63.0

1, USNM S16; 2-3, IDG X829, X1183; 4, IGS 1893; 5, WC 77; 6, UC 25019; 7-8, UCWM 26482 A, B.

Order MONOBATHRIDA Moore & Laudon, 1943

[Ord.-Perm.]

Suborder TANAOCRININA Moore, 1952

[Ord.-Perm.]

Family ACTINOCRINITIDAE Austin & Austin, 1842 (BASSLER, 1938)

[Miss.-Perm.]

[*nom. subst.* Bassler, 1938, p. 27 (*pro* Actinocrinidae Austin & Austin, 1843, p. 199, *nom. correct. pro* family Actinocrinoidea Austin & Austin, 1842, p. 109).]

Genus ACTINOCRINITES J. S. Miller, 1821

[Sil.-Perm., N.Am.-G.Brit.-Eu.]

Actinocrinites is represented in Crawfordsville material studied by a single specimen of *A. gibsoni*. Several specimens labelled *Actinocrinites* were found to be bato-crinids; however, because many large collections could not be examined other specimens of this genus undoubtedly came from this locality. WACHSMUTH & SPRINGER's *A. multiramosus*, considered a junior synonym of *A. gibsoni* herein, is represented by over 40 well-preserved specimens from Indian Creek and their *A. magnificus* was also rather abundant at this locality.

BASSLER & MOODEY (p. 92, 271) recorded HALL's *A. lobatus* from Crawfordsville, but examination of published descriptions of this species failed to confirm this. Ten specimens sent to me were referred to *A. lobatus*, but the locality was indicated as "questionably from Crawfordsville." The matrix was so different from known rocks occurring at Crawfordsville that it is reasonable to assume that the specimens came from some other locality, and thus they are not included in the present study.

Actinocrinites gibsoni (MILLER & GURLEY, 1894)

BASSLER & MOODEY, 1943

Actinocrinus gibsoni MILLER & GURLEY, 1894, p. 10, pl. 2, fig. 1.
Actinocrinites gibsoni BASSLER & MOODEY, 1943, p. 269.

Actinocrinus multiramosus WACHSMUTH & SPRINGER, 1897, p. 564, pl. 53, fig. 1; pl. 55, fig. 3.

Actinocrinites multiramosus BASSLER & MOODEY, 1943, p. 272.
non Actinocrinus grandis MILLER & GURLEY, 1890 (June ed.), p. 25, pl. 5, fig. 7; pl. 6, fig. 1.

Diagnosis. Theca obconical to distal edge of IBrr₁, broadly truncate at base; dorsal cup plates heavy, convex, with well-defined ridges that traverse suture lines, and large nodes near middle of plates, some in lower part of cup transversely elongate; BB large, expanded proximally into a smooth, thickened, trilobate rim; tegmental plates slightly convex, moderately large; arms long, moderately heavy, not uniformly tapering distally.

Remarks. Only a single, partly broken specimen (NYSM no. 11486) of *Actinocrinites gibsoni* was available for my study and nothing significant can be added to previous descriptions of the species. WACHSMUTH & SPRINGER's monograph on camerate crinoids was in press

when MILLER & GURLEY described *A. gibsoni*, and thus this name has priority over *A. multiramosus* (WACHSMUTH & SPRINGER). Previously MILLER & GURLEY (1890) described *A. grandis* from Washington County, Indiana; however, this name was preoccupied (LYON & CASSEDAY 1859, p. 240) and thus it is a primary homonym. MILLER & GURLEY's name was questionably considered a synonym by WACHSMUTH & SPRINGER (1897, p. 564) of *A. multiramosus* and also placed in synonymy of this species by BASSLER & MOODEY (1943, p. 272). Examination of the type of *A. grandis* clearly indicates that it is an entirely different species and was renamed *A. grandissimus* by me (1964).

Of particular interest is the fact that WACHSMUTH & SPRINGER (1897, p. 566) reported approximately 20 specimens with either *Platyceras* attached to the tegmen, or *Onychaster* coiled around the anal tube.

Actinocrinites gibsoni most closely resembles *A. magnificus* (WACHSMUTH & SPRINGER), but the latter can be distinguished by its much larger and more elongate dorsal cup, well-developed ridges produced by folds on the cup plates, numerous iRR, and shorter, more slender tapering arms.

Type. MILLER & GURLEY's type is UCWM no. 6631 and one of WACHSMUTH & SPRINGER's syntypes of *A. multiramosus* is USNM no. S-1170.

Occurrence. This species is restricted to the Borden beds in Montgomery County, Indiana. It is represented by approximately 40 well-preserved specimens in the Springer Collection from Indian Creek but was apparently rare in the Crawfordsville crinoid beds.

[*Actinocrinites lobatus* (HALL, 1860)
BASSLER & MOODEY, 1943]

BASSLER & MOODEY (p. 92, 271) state that this species has been reported from Crawfordsville, but published descriptions do not confirm this.

Family BATOCRINIDAE Wachsmuth & Springer, 1897

[Miss. (U. Kinderhook-L. Chester), N. Am.]

The batocrinids are one of the most abundant groups of camerate crinoids known and some species are represented by extraordinarily large numbers of individuals. Study by LANE (1958), although unpublished, not only contributed much to understanding of morphological features and evolution among batocrinids and camerates in general, but showed that considerable individual variation exists in the camerates. Many characters previously considered to be of specific value were demonstrated to represent merely natural variations within species populations. Study of rather extensive collections of batocrinids from Crawfordsville not only confirms LANE's conclusions, but indicates that in some groups even more variation existed than he recognized. Some of LANE's results and description of two new batocrinid genera were published recently (1963a); however, students of

this group of crinoids are advised to consult his unpublished thesis, since much information contained in it will not be included in the paper just cited.

Prior to LANE's revision of this family nine genera and approximately 217 species were assigned to the Batocrinidae. Many previously named species were differentiated solely on the basis of slight differences in the total number of arms or the number of arms in particular rays. Study of relatively numerous specimens which now are judged to represent a single species indicates that many nominal species should be considered to be junior synonyms. LANE recognized only 78 valid species (Table 31).

The primary reasons for this large reduction in number of species accepted as valid can be illustrated best by reviewing species assigned to *Batocrinus* type-genus of the family. Prior to 1958, 135 species had been assigned to this genus. Of these, 106 were described by S. A. MILLER and MILLER & GURLEY when genera now assigned to Batocrinidae had not been named and LYON & CASSEDAY's *Eretmocrinus* was considered by MILLER & GURLEY to be a synonym of *Batocrinus*. Consequently all batocrinids described by these authors were called *Batocrinus* and many are now placed in other genera of the family. Further, MILLER & GURLEY believed that the single most important character of specific importance is the number of arms in each ray. This concept of speciation allows no individual variation in arm structure; however, as shown by LANE, the arms are among the most variable features in many camerate genera. Undoubtedly, similar revisions of many crinoid families will also result in decrease of valid species recognized.

TABLE 31. Comparison of Batocrinid Species Recognized as Valid Prior to 1958 with Those Recognized by Lane.

Genera	Number of Species	
	Pre-1958	LANE, 1958 1963
<i>Abatocrinus</i> LANE		15
<i>Alloprosalocrinus</i> CASSEDAY & LYON	2	1
<i>Azygocrinus</i> LANE		3
<i>Batocrinus</i> CASSEDAY	135	7
<i>Dizygocrinus</i> WACHSMUTH & SPRINGER	28	12
<i>Eretmocrinus</i> LYON & CASSEDAY	27	19
<i>Eutrochoocrinus</i> WACHSMUTH & SPRINGER	4	4
<i>Globocrinus</i> WELLER	1	1
<i>Macrocrinus</i> WACHSMUTH & SPRINGER	6	5
<i>Sunwaptocrinus</i> LAUDON, PARKS & SPRENG	1	Not batocrinid
<i>Uperocrinus</i> MEEK & WORTHEN	13	11
Total	217	78

Genus ABATOCRINUS Lane, 1963

[Miss., Iowa, Ind., Ky., Tenn.]

Lane (1963a) proposed *Abatocrinus* for 16 species ranging in age from Kinderhookian into Keokuk time;

previously all of these were assigned to *Batocrinus*. *Abatocrinus* is distinguished from *Batocrinus* in having a higher, narrower dorsal cup, more prominent B circlet, less prominent tegmen which is not strongly nodose or spinose, and small semicircular arm facets with fine radial striations. The only significant taxonomic character that is shared by the two genera is arching of all interrays by BrrF; because several other batocrinid genera also exhibit this feature, it cannot be considered to be significant in defining genera.

As now understood, *Abatocrinus* arose from an *Aorocrinus*-like ancestor in Kinderhookian time. The genus culminated in the lower Burlington, but continued through the upper Burlington and finally became extinct in rocks of Keokuk age. *Batocrinus* is judged to have evolved from Keokuk species of *Dizygocrinus* and is restricted to beds of Warsaw, Salem, and Ste. Genevieve age.

Abatocrinus is represented in the Crawfordsville beds by *A. grandis*, a large, advanced form of the genus. It and the other known Keokuk form, *A. steropes*, are easily distinguished from Burlington species by their larger, more nodose theca, more abundant arms, and the development of fewer iRR.

The occurrence of specimens bearing paired arms is of utmost interest; however, in my opinion this merely necessitates a slight revision to LANE's description of the genus. It supports judgment that arm structure is so variable that it has little significance as a taxonomic feature in defining species, and in most cases genera of batocrinids and other camerate families. The fact that paired arms have not been previously reported in this genus is the result of (1) most batocrinids do not have the arms preserved, (2) early investigators commonly had only a few species available for study, thus, comparisons of individual variations could not be recognized or studied, and (3) the desire on the part of early workers merely to describe as many new species as possible and not to re-study faunas. All specimens of *A. grandis* are so similar in all features of the theca that no need for detailed studies of arms was necessary to identify them. As a result, collectors and curators with little understanding of crinoid paleontology could easily identify this species by gross aspects of the theca.

Abatocrinus grandis (LYON & CASSEDAY, 1859)

LANE, 1963

Plate 7, fig. 5-8; text-fig. 17,2; 19,4; 36

Actinocrinus sp. nobis (*grandis*) LYON & CASSEDAY, 1859, p. 240, 241.

Batocrinus grandis WACHSMUTH & SPRINGER, 1897, p. 381, pl. 1, fig. 2; pl. 27, fig. 1a, b, 2a, b, p. 567.

Abatocrinus grandis LANE, 1963a, p. 697.

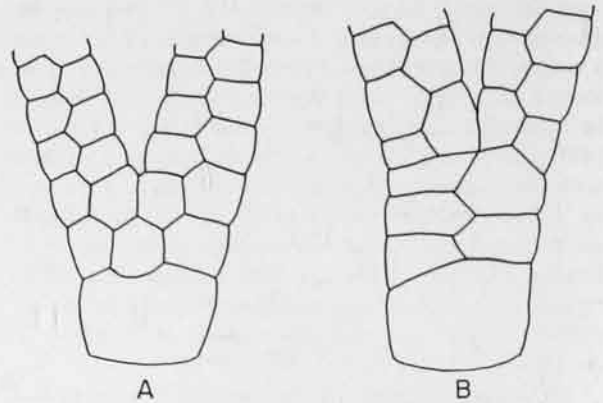


FIGURE 36. Diagrammatic representation of proximal portion of paired arms of *Abatocrinus grandis*.—A. Normal development of brachials in which initial plate is uniserial and subcentral, X4.—B. Abnormal specimen (WC no. 74) showing initial single biserial arm bifurcating into paired arms (X4).

Actinocrinus wachsmuthi WHITE, 1880, p. 162, pl. 40, fig. 1a, b; 1881, p. 510, pl. 7, fig. 6 (non WHITE, 1862, = *Actinocrinites scitulus*).

Actinocrinites urna TROOST, 1849, p. 419, *nom. nud.*

Diagnosis. Theca large, with strong nodose plates; BB having prominent transverse proximal nodes that extend down around stem, arms 22 to 26, commonly single, rarely paired.

Description. Dorsal cup large, gradually expanding from RR to IIAXx, then abruptly to base of free arms; plates convex, nodose, BB, RR, IBrr, and IIBrr bearing transverse nodes that decrease in width distally; Anals with prominent central nodes, IIIBrr with small nodes or flat. BB wide, thickened in proximal portion, interbasal sutures deeply grooved; RR and IBrr large, 4 IIBrr, each IIAXx followed by 6 to 8 IIIBrr in A, B, and E-rays; IIIBrr₁₋₂ may be axillary; iRR 3 to 4, all arched by BrrF; anal X large, narrower than RR, but slightly higher, followed by 6 to 9 Anals. Tegmen of medium height, sides convex, plates large, those on posterior side commonly smaller, bearing small- to medium-sized nodes, circular or slightly elongate in shape; anal tube long, subcentral, extending above distal end of arms, plates nodose. Arms 22 to 26, commonly single, rarely entirely or partly paired, 4 Amb openings in A, B, and E rays and 4 to 7 in C and D rays, long, slender, commonly slightly flattened distally; arm facets small, directed obliquely upward, arm ossicles subtriangular in out-line. Stem large, nodals considerably larger than internodals and angular at their edges.

Remarks. The trivial name *grandis* was omitted from the title of the original description, but LYON & CASSEDAY used it when comparing this species with closely related forms (p. 241). Thus, the name is properly credited to LYON & CASSEDAY, although some bibliographic sources

(e.g., WELLER, 1898, p. 127) cite WACHSMUTH & SPRINGER as authors of the species. Many specimens in museum collections credit only LYON as the author, probably because it was cited in this manner in WACHSMUTH & SPRINGER's monograph (1897, p. 381). WHITE's *Actinocrinus wachsmuthi* differs in no way from a typical average-sized specimen of *Abatocrinus grandis*.

The presence of specimens with paired arms is significant in emphasizing the amount of variation found in arm structure of batocrinids and camerate crinoids in general. This variation is best shown from the Crawfordsville material in *Dizygocrinus indianaensis*, which has 1, 2, 3, or 4 arms originating from a single Amb opening. The presence of paired arms in *Abatocrinus* has not been reported before and might be used as the basis for recognizing a new genus except that no other significant feature separates the dorsal cups of single and paired-armed specimens (Fig. 36). The presence of both types of arms on a single individual supports the conclusion that arm structure alone is not a valid criterion for proposal of a new genus.

Paired arms developed in *Abatocrinus grandis* are constructed in a similar manner to those observed in *Dizygocrinus*. The initial Br is uniserial and in a sub-central position. It supports more distal Brr that are arranged biserially. The innermost Brr are somewhat smaller and commonly in contact with each other laterally. The only observed variation (WC no. 74) has one biserial arm that developed initially as a single arm, but above the first 3 Brr the arm splits into two dichotomous biserial arms (Fig. 36-B).

Abatocrinus grandis can be distinguished from the only other known Keokuk species, *A. steropes* (HALL, 1860), by its smaller size, more numerous arms, and fewer iRR. *Eretmocrinus magnificus* LYON & CASSEDAY, 1859 resembles *A. grandis* in large size of the nodose tegmen, and superficially in appearance of the BB. The large lobed transverse nodes on the BB of the latter

species somewhat resembles the slightly concave base of *E. magnificus*, but the two species are totally different.

Curatorial Problems. Many specimens of *Abatocrinus grandis* are mislabelled *Eretmocrinus magnificus*, resulting largely from misinterpretation of the nature of BB as discussed above. Further, the author of *A. grandis* is commonly incorrectly given as LYON or WACHSMUTH & SPRINGER.

Type. The holotype is USNM no. S-1084. One of WHITE's syntypes of *Actinocrinus wachsmuthi* is UC no. 3256 and TROOST's type of *Actinocrinus urna* is USNM no. 39896.

Occurrence. Known from Borden beds at Crawfordsville, and from the Ft. Payne Chert at White Creek Springs, Tennessee.

Material. Thirty-five specimens were available for my study, of which 17 were selected for measurements.

Dimensions. Measurements made on selected specimens available for study are shown on Table 32.

Genus ALLOPROSALLOCRINUS Casseday & Lyon, 1862

[Miss. (Keokuk), Ky., Ind., Tenn.]

This monotypic genus closely resembles, and according to LANE (1958), is directly derived from the coelocrinid genus, *Agaricocrinus*. Both have almost flat dorsal cups, high prominent tegmens, and the same number of arms (10 to 12) articulating from large circular arm facets. However, *Alloprosallocrinus* has a well-developed anal tube and BrrF that arch over the iRR. It is quite distinct from other batocrinid genera in general appearance, but in features used to define the family it unquestionably belongs to the Batocrinidae.

Previous authors (e.g., WACHSMUTH & SPRINGER, 1897; SPRINGER, 1913; LANE, 1958) placed importance on the fact that most specimens of *Alloprosallocrinus conicus* possess only a single IBr in each ray. It has been suggested that the IBrr₁ have been ankylosed so that these plates form the proximal portion of the IAxx. Evidence from a well-preserved specimen used in this study (discussed below) shows that the IBrr₁ were probably eliminated from the dorsal cup rather than fused with the IAxx as suggested by previous authors. The presence

TABLE 32. Measurements of *Abatocrinus grandis* in mm.

Measurements	Specimens																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dorsal cup height	28.6	23.7	24.6	28.0	26.0	17.5	26.7	16.4	29.7	22.0	30.0	25.0	15.0	22.0	24.0	31.0	27.8
Dorsal cup width	34.8	30.9				26.8	31.0	24.2	38.0				25.0		33.0	34.0	
Basal circllet height	4.4	5.2	5.0	5.0	5.0	4.0	5.5	3.5	4.0	4.7	5.5	4.0	3.0	4.5	4.0	3.2	4.7
Basal circllet width	12.4	13.1	12.7		12.2	9.5	14.0	10.0	12.0	10.8	12.5	12.5	9.0	11.5	12.0	15.0	12.5
Stem diameter	8.3	6.9	7.3	10.0	6.2	5.0	6.5	6.0	6.5	5.6	7.3	7.5	5.0	6.5	7.0	10.0	8.0
Tegmen height	15.0	19.0	17.0				19.0	12.0		18.0	18.0	20.5			17.0	21.0	17.0
Number of arms			23	23	24	22	25	23	25		24	22			23	23	
Arm length					72.0	47.0								41.0			
Arm facet height	2.3	3.0	2.7	3.0	2.4		3.0	2.0			4.0	2.5		2.5			3.5
Arm facet width	2.7	2.3	2.8	3.0	2.6		2.4	2.5			3.0	2.7		2.6			3.4

or absence of these plates is merely a matter of individual variation in the growth of the individual and not of significant taxonomic importance. In most specimens the $IBrr_1$ are axillary.

Alloprosallocrinus conicus CASSEDAY & LYON, 1862

Plate 7, fig. 2-4; text-fig. 17,5; 11, 37

Alloprosallocrinus conicus CASSEDAY & LYON, 1862, p. 29; WACHSMUTH & SPRINGER, 1897, p. 407, pl. 42, fig. 14; ROWLEY, 1906, p. 10, pl. 3, fig. 14, 15; WOOD, 1909, p. 71.

Alloprosallocrinus gurleyi MILLER, 1892a, p. 668, pl. 10, fig. 1, 2.

Alloprosallocrinus tuberculatus WOOD, 1909, p. 69, pl. 5, fig. 14, 15.

Conocrinites leae TROOST, 1849, p. 419, *nom. nud.*

Conocrinites tuberculatus TROOST, 1849, p. 419, *nom. nud. non*

Alloprosallocrinus celsus MILLER & GURLEY, 1894, p. 47, pl.

4, fig. 9-11 (= ?*Eretmocrinus praegravis*); *non Alloprosallo-*

crinus depressus CASSEDAY & LYON, 1862, p. 31 (= *Agarico-*

crinus? *depressus*).

Diagnosis. Dorsal cup almost flat, basally impressed bowl-shaped; $IBrr_1$ partly developed or absent, commonly being eliminated from dorsal cup; tegmen high, conical, anal tube stout, subcentral; arms 10 to 12.

Description. Theca subpyramidal, dorsal cup plates almost invisible from side view, smooth. BB short, recessed in center for reception of stem; RR wider than high, proximal portions bent inward forming part of recessed center; $IBrr_1$ commonly eliminated from cup, more rarely fully developed or greatly reduced in size so that part of proximal sutures of IA_{xx} are in contact with RR below; 10-armed specimens have 4 $IIBrr_1$ in each ray above IA_{xx} , specimens with an additional arm in C and D rays having the posterior $IIBrr_1$ axillary and supporting 2 or 3 $IIIBrr_1$ on each side; distal $BrrF$ elongate, outer portions arcuate, curving distally, in contact with $BrrF$ of adjoining rays; iRR large, arched by $BrrF$; anal X and 3 Anals in CD interray, all arched by $BrrF$; thecal pores large and prominent, located to side of Amb openings toward theca. Tegmen high, conical, straight-sided, rising abruptly from margins to anal tube, composed of large nodose plates; anal tube large, subcentral, or arising toward anterior side in specimens that have orals pushed to anterior side. Arms 10 to 12, structure unknown, but judging from size and shape of arm facets, they were large and well-developed; arm facets large, crescent-shaped, and directed slightly upward, each facet composed of portions of 2 different $BrrF$, one of which overlaps slightly so that in the median portion of the facet the uppermost $BrrF$ is slightly higher; facets located on inner sides of $BrrF$ toward median axis of each ray, rather than occupying middle of the plate so that arms appear grouped.

Remarks. Five species of *Alloprosallocrinus* have been described; however, all but *A. conicus* are considered to be synonyms or are invalid. MILLER'S *A. gurleyi* (1892) is similar in all significant taxonomic characters except number of arms, and is considered

merely a morphological variant of *A. conicus*. The former has 11 arms, 3 being developed in the C ray. *A. celsus* and *A. depressus* do not belong to this genus and should be referred to forms of *Eretmocrinus* and *Agaricoerinus*, respectively. WOOD'S *A. tuberculatus* ap-

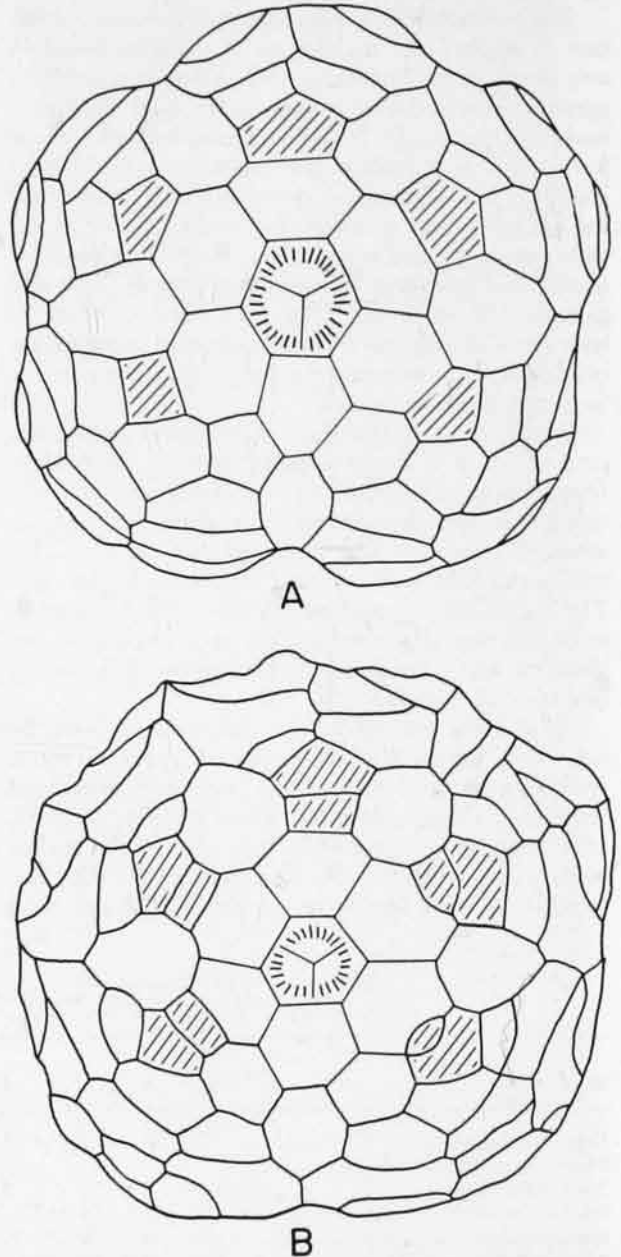


FIGURE 37. Dorsal view of *Alloprosallocrinus conicus*, showing arrangement and number of primibrachs.—A. Typical arrangement of dorsal cup plates with a single primibrach (axillary) in each ray, X2.—B. Abnormal specimen (UCWM no. 8922) with two primibrachs in each ray suggesting that the first primibrachs are eliminated from the theca rather than ankylosed as thought by previous authors, X2. [EXPLANATION: Primibrachs ruled.]

pears to be properly assigned to the genus; however, the specimens upon which the description was based have been subsequently lost (Wood, 1909, p. 70) and until found it is considered a synonym of *A. conicus*. TROOST (1849) first used the name *tuberculosis*, but the species was not described and illustrated until WOOD published TROOST's manuscript. *A. tuberculosis* supposedly differs from *A. conicus* in having large iRR that are in contact with the tegmen in all interrays and in having spines on the tegmen. However, it is possible that TROOST mistook the arcuate outer portion of the distal BrrF for iRR, which they closely resemble.

The development of IBrr in *Alloprosallocrinus* is interesting and deserves special note. WACHSMUTH & SPRINGER, as well as others, have suggested that one feature of particular taxonomic importance is that the IBrr₁ are fused with the IAxx so that only a single distinct pentagonal axillary plate is visible. One specimen examined, however, has 2 IBrr developed in the A, B, and C rays and in the D and E rays this plate is reduced in size, so as not to extend the entire width of the RR. Consequently, part of the proximal sutures of the IAxx are in contact with the RR (Fig. 37-B). This peculiar development suggests that the IBrr₁, rather than being ankylosed with the IAxx, may become so reduced in size that it is eventually eliminated from the dorsal cup of typical specimens of *Alloprosallocrinus*. The rather short sides of the plates in forms with only a single IBrr in each ray also indicates that elimination, rather than fusion, has occurred. If plates had been fused, one would expect the sides of the single enlarged IAxx to be relatively long.

Type. Two syntypes (USNM no. S 783A,B) were designated by CASSEDAY & LYON. Specimen S-783A, the better preserved and more complete specimen, is herein selected as lectotype.

Occurrence. This species has been reported from the Ft. Payne Chert at Whites Creek Springs, Tennessee, and from Hardin, Barren, and Metcalf Counties and Knob, south of Louisville, Kentucky. It is rare in the Borden beds of Montgomery County, Indiana.

Material. In addition to plaster casts of the types, a single well-preserved specimen from Crawfordsville (UCWM no. 8922) was available for study.

Dimensions. Measurements of specimens assigned to this species are shown on Table 33.

Genus DIZYGOCRINUS Wachsmuth & Springer, 1897

[Miss. (Keokuk, Warsaw), Ill.-Ind.-Ky.-Mo.-Tenn.]

LANE (1963) proposed the genus *Azygocrinus* for Burlington species formerly referred to *Dizygocrinus*, and as now known, the latter is restricted to beds of Warsaw and Keokuk age. *Azygocrinus* lacks ornamentation such as nodes and ridges, distinct sutures between plates of dorsal cup, and paired arms.

One of the most characteristic features of *Dizygocrinus* is the presence of paired arms, which originate from a single Amb opening. Commonly, both single and

double (paired) arms occur on the same specimen; however, variants with all single arms to those in which all the arms are paired were observed in the Crawfordsville species *D. indianaensis*. One highly abnormal specimen has as many as 4 arms arising from a single Amb opening. The great majority of specimens studied possess paired arms, and more rarely a few single arms are developed with the paired ones. Only one specimen was observed with all single arms.

The structure of the proximal portion of the double arms in *Dizygocrinus* is similar to those reported here for the first time in *Abatocrinus grandis*. The mode of development in *Eutrochocrinus*, which is the only other batocrinin reported to have double arms, is quite different. In *Eutrochocrinus* all Amb openings possess paired arms and the proximal portions of the arms are eventually incorporated into the dorsal cup of some specimens.

Specimens of *Dizygocrinus* form one of the most abundant components of the camerate fauna in beds in which they occur. Of the 3 species described from Crawfordsville, specimens of *D. indianaensis* are most abundant in number of individuals found. *D. crawfordsvillensis* and *D. montgomeryensis* are represented by only 2 and 4 known specimens, respectively.

Dizygocrinus crawfordsvillensis (MILLER, 1891)

WACHSMUTH & SPRINGER, 1897

Batocrinus crawfordsvillensis MILLER, 1891, p. 64, pl. 10, fig. 11, 12; 1892a, p. 674, pl. 10, fig. 11, 12.

Dizygocrinus crawfordsvillensis WACHSMUTH & SPRINGER, 1897, p. 417; LANE, 1963, p. 699.

Batocrinus decrepitus MILLER, 1892c, p. 34, pl. 5, fig. 24; 1894, p. 288, pl. 5, fig. 24.

Diagnosis. Dorsal cup small, sides gently convex to nearly straight; strong radiating ridges on iRR₁, thin well-defined angular ridges along median portion of RR and BrrF, arms 16 to 18, paired, short.

Description. Theca small to medium-sized; dorsal cup plates with ridges from RR to distal BrrF and transverse ridges on RR and anal X, BB low, slightly wider than column; RR considerably wider than long, elevated above interrays; iRR 3 to 5, appearing depressed because of well developed ridges on BrrF; 3 to 4 IIIBrr above each IIAXx. Anal X followed by 3 anals in first

TABLE 33. Measurements of *Alloprosallocrinus conicus* in mm.

Measurements	Specimens		
	USNM S783A	USNM S783B	UCWM 8922
Dorsal cup height	4.2	7.9	8.0
Dorsal cup width	26.3	32.7	32.8
Tegmen height			17.2
Arm facet height			6.0
Arm facet width			6.2

circlet, and two in distal portion of interradius. Tegmen convex, composed of small nodose plates; anal tube long, slender, central. Arms short, delicate incurved, and extending slightly above tegmen; 16 to 18, paired, 2 in *A* ray, 3 or 4 in *C* and *D* rays, and 4 in *B* and *E* rays.

Remarks. *Dizygocrinus crawfordsvillensis* was rare in the Crawfordsville crinoid beds and only two specimens were found in the collections studied. *D. decrepitus* differs from *D. crawfordsvillensis* only in having an additional paired arm in the *C* and *D* rays and is herein considered to be a synonym of the latter species. Ornamentation of the dorsal cup superficially resembles *D. indianaensis*, with which it is associated, but it can be easily distinguished by its short, delicate arms.

Type. MILLER's type, UCWM no. 6492, was preserved in an oily solution and parts of the specimen have been softened and broken. The holotype of MILLER's *Batocrinus decrepitus* is USNM no. S-836. The only specimens available for study were the types.

Occurrence. This species is known only from the Crawfordsville crinoid beds.

Dimensions. Measurements of specimens of this species are given on Table 34.

TABLE 34. Measurements of *Dizygocrinus crawfordsvillensis* in mm.

Measurements	Specimen	
	USNM 6492	USNM S836
Dorsal cup height	8.2	8.9
Dorsal cup width	12.2	16.2
Basal circling height	1.1	1.0
Basal circling width	5.1	5.0
Stem diameter	3.0	3.3
Tegmen height		5.7
Arms length	10.0	12.3

Dizygocrinus indianaensis (LYON & CASSEDAY, 1860)
WACHSMUTH & SPRINGER, 1897

Plate 8, fig. 5-8; text-fig. 13, 1, 7; 38; 38; 40

Actinocrinus indianaensis LYON & CASSEDAY, 1860, p. 75.

Dizygocrinus indianensis (misspelling) WACHSMUTH & SPRINGER, 1897, p. 415, pl. 33, fig. 6a, b; pl. 35, fig. 5.

Dizygocrinus indianaensis LANE, 1963a, p. 699.

Dizygocrinus indianensis var. *simplex* WACHSMUTH & SPRINGER, 1897, p. 416, pl. 33, fig. 7.

Diagnosis. Theca large, subglobose; dorsal cup plates with irregular nodes and ridges; BrrF with strong radial ridges; all interrays in contact with tegmen; arms typically 18, paired, rarely partly single.

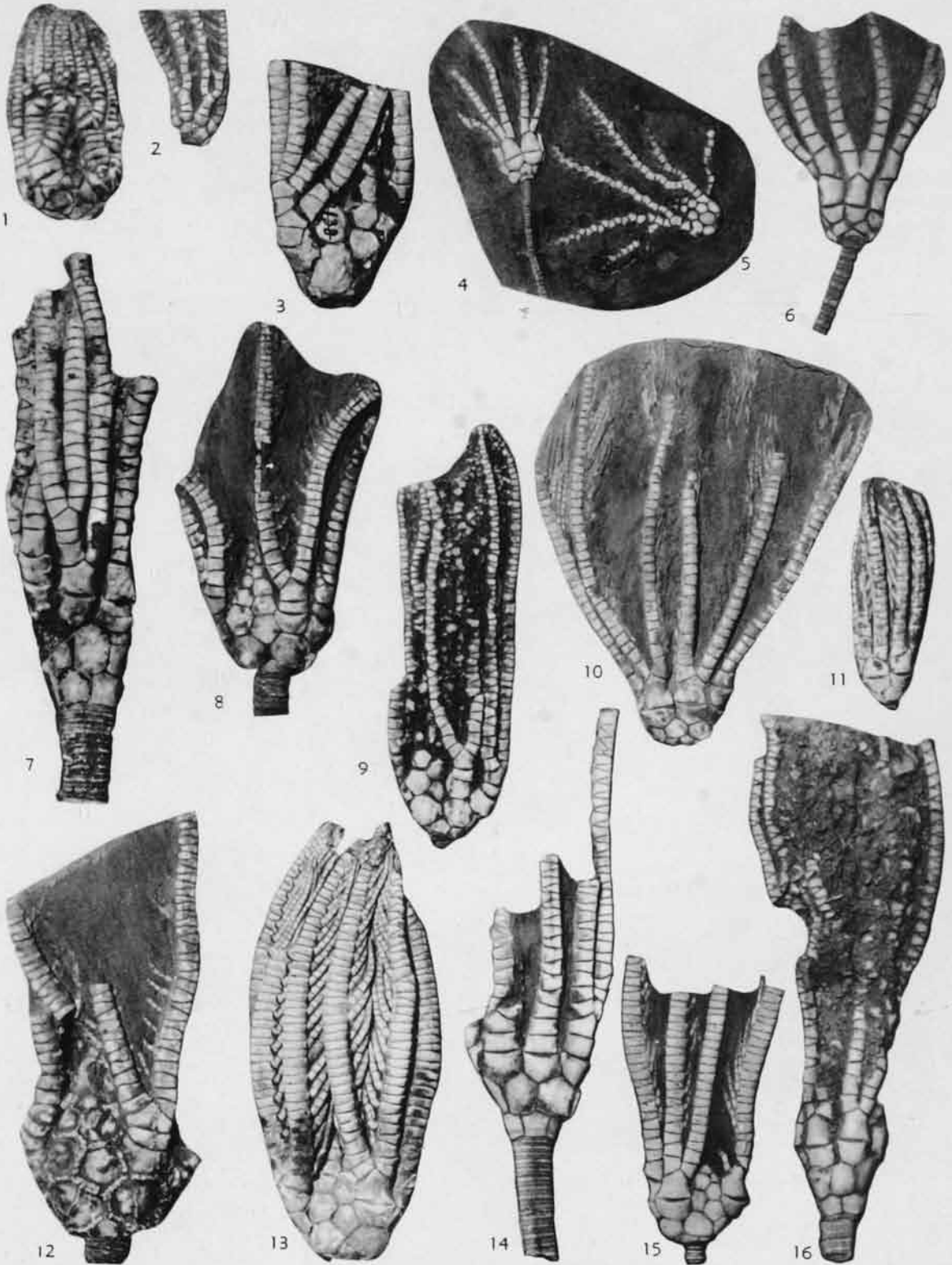
Description. Theca about as high as wide; dorsal cup slightly higher than tegmen, with gently convex sides from top of B circling to arms; all plates ornamented with strong irregular nodes and ridges from RR to distal BrrF. BB short, wide, projecting slightly below proximal columnal, restricted distally; RR wider than long, strong transverse ridges confluent with radial ridges; iRR commonly 5, rarely 6, all in contact with tegmen; IB₁ quadrangular, shorter and narrower than RR, IB₂ commonly heptagonal, wider than IB₁; IIB₁ typically 4 in each ray, IIB₂ axillary except in *A* ray 3; IIB₁ below each arm opening. Anal X narrower than RR, heptagonal, followed by 7 to 12 Anals. Tegmen straight-sided, of medium height, composed of small nodose plates; anal tube long, narrow, subcentral. Arms typically 18, paired, with 2 in *A* ray, more rarely 16, 17, or 20 arms some of which may be unpaired, long, tapering distally.

Remarks. In more than 40 specimens examined, all possessed 18 paired arms, with 2 arms developed in the *A* ray and 4 in each of the other rays. Considerable

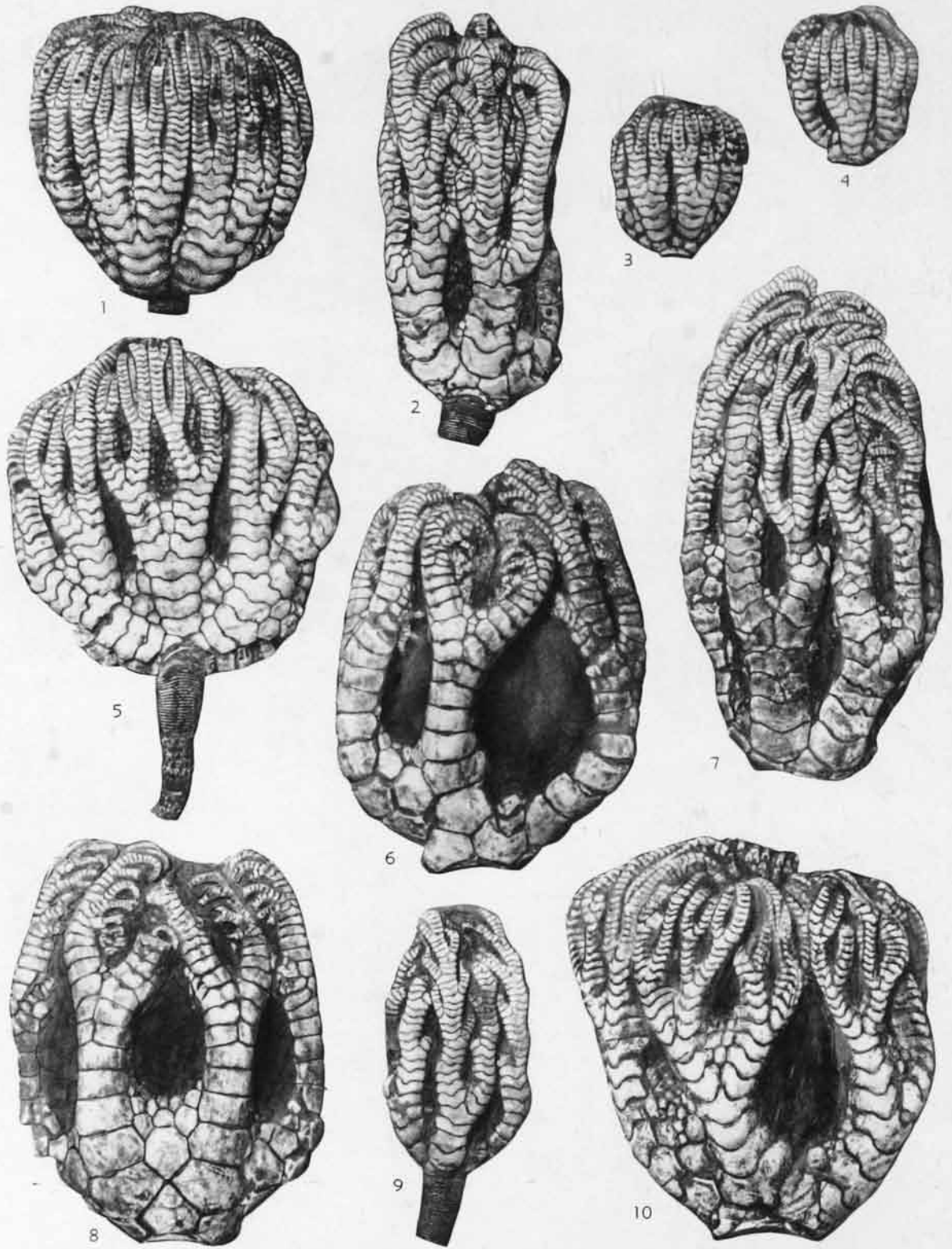
EXPLANATION OF PLATE 5

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE		PAGE
1.		<i>Sarcocrinus granilineus</i> (MILLER & GURLEY); <i>CD</i> view of holotype (UCWM 6260)	98
2,5.		<i>Histocrinus graphicus</i> (MILLER & GURLEY); 2, <i>BC</i> view of crown (NYSM 1480); 5, <i>CD</i> view of holotype (UCWM 6170A)	94
3,7,14.		<i>Hypselocrinus indianaensis</i> (MEEK & WORTHEN); 3, <i>CD</i> view of holotype (ISM 10133, X1089); 7, ? <i>B</i> ray view of MILLER & GURLEY's holotype of <i>Poteriocrinus crawfordsvillensis</i> (UCWM 6398); 14, <i>A</i> view of incomplete crown (UC 25032A)	95
4,6.		<i>Scytalocrinus disparilis</i> (MILLER & GURLEY); 4, ? <i>EA</i> view of lectotype (UCWM 6170B); 6, ? <i>A</i> ray view of crown with attached part of stem (UCWM 6171, not holotype, as marked), $\times 2$	96
8,9,12.		<i>Histocrinus coreyi</i> (WORTHEN); 8, <i>CD</i> view of crown (UCWM 8911D); 9, <i>C</i> ray view of another specimen (UCWM 8911A); 12, <i>CD</i> view of incomplete large crown (UCWM 8911B)	93
10,11,13,15.		<i>Scytalocrinus robustus</i> (HALL); 10, <i>EA</i> view of crown (WC 17); 11, <i>AB</i> view of small crown (ISM 10167); 13, <i>CD</i> view of robust crown showing thick arms and stout pinnules (YPM 6444A); 15, <i>CD</i> view of incomplete crown (UCWM 51826)	97
16.		<i>Hypselocrinus hoveyi</i> (WORTHEN); <i>D</i> ray view of specimen doubtfully assigned to this species (NYSM 11481)	95



VAN SANT & LANE—Crawfordsville Crinoids



VAN SANT & LANE—Crawfordsville Crinoids

variation, however, exists in the number of arms originating from a single Amb opening in some specimens and in the structure of the fixed-brachials.

Fixed-brachials, which represent proximal portions of the arms in larval stages that are incorporated into the dorsal cup in the adult stage, vary in number and arrangement of plates (Fig. 38). Two IBrr commonly are followed by 2 IIBrr except in the portions of the rays that do not branch above the IAxx. The *A* ray in all specimens observed bears 2 paired arms that begin on the IIBrr₄. Other rays may also partly have only IIBrr developed, but these are not constantly oriented as in the *A* ray. Four or 5 IIBrr are common in portions of the rays not possessing IIIBrr, and in those rays in which IIIBrr are present, 3, 4, or 5 IIIBrr develop. The greater number commonly is found adjoining the CD-interray where a greater distance needs to be arched by the BrrF because of the development of large Anals.

Single arms seem to develop in no consistent arrangement and their location appears to be completely at random. The structure differs from those observed in *Abatocrinus* in that the initial Br is not a single plate, but the biserial condition begins at the most proximal portion of the arms and continues distally. Single arms normally do not differ in size and shape from individual arms of a pair; however, WACHSMUTH & SPRINGER (1897, p. 416, pl. 35, fig. 5) described an abnormal specimen in which the size and shape of the arms varied considerably. It has 12 single arms and 6 paired ones with some arms of greater width. Seven of the 12 single arms are twice as long as the others, which have the same length and width as paired arms. This difference indicates that the specimen originally had single arms and that the smaller paired arms probably replaced ones that were injured and discarded or broken off.

Paired arms are typical for this species and most specimens have them entirely developed in all rays; however, variations from 13 to 18 pairs were noted. Specimens with 3 and 4 arms originating from a single Amb opening are extremely rare (Fig. 39). On Brr in which 3 arms are borne, a single rather large plate, similar to the initial plate in paired arms, is followed by 2 Brr upon which the 3 biserial arms are developed. No crowding of the arms is apparent and the arm widths correspond closely to those of more typical paired ones. However, in specimens with 4 arms, the most proximal portion begins with 2 initial plates arranged laterally. The outer arms are slightly twisted, so that the sutures between the biserial plates are not facing outward but are along the sides in the proximal portion of the arms. This abnormal development was undoubtedly caused by crowding because of the greater number of arms.

The number of arms appears to be developed early in the ontogeny of an individual. Except for the abnormal specimen described by WACHSMUTH & SPRINGER, no evidence is found that any of the arms were the result of reconstruction because of injury. The increase in number of arms is judged to be genetic and not phylogenetic. The number of arms developed did not seem to add any particular advantage in feeding, as one might expect, because individuals with 13 pairs of arms are just as robust as those with 16 or 18 pairs.

The number and arrangement of Anals also shows considerable variation in *Dizygocrinus indianaensis* (Fig. 40). Most commonly 10 anals are present above anal X; however, the observed variation ranges from 7 to 12. Constant development of plates was found only in the cirlet of 3 Anals directly above the anal X. The number and size of plates in the CD-interray varies with different size and shape of dorsal cups.

EXPLANATION OF PLATE 6

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE	
1,3-5,10.		<i>Taxocrinus colletti</i> WHITE; 1, AB view of typical crown showing globular form (UCWM 51835C); 3,4, EA and C views of small crown (UCWM 8933A); 5, A ray view of neotype (UCWM 26479); 10, CD view of robust crown (UCWM 7054) 103
2,7,9.		<i>Onychocrinus ramulosus</i> (LYON & CASSEDAY); 2, A ray view of typical crown (UCWM 51834B); 7, DE view of larger specimen (UCWM 51834A); 9, D ray view of small crown with proximal portion of attached stem (NYSM 11485) 101
6,8.		<i>Onychocrinus ulrichi</i> MILLER & GURLEY, Indian Creek; 6, CD view of typical specimen (UCWM 6169); 8, AB view of another crown (UCWM 6169) 100

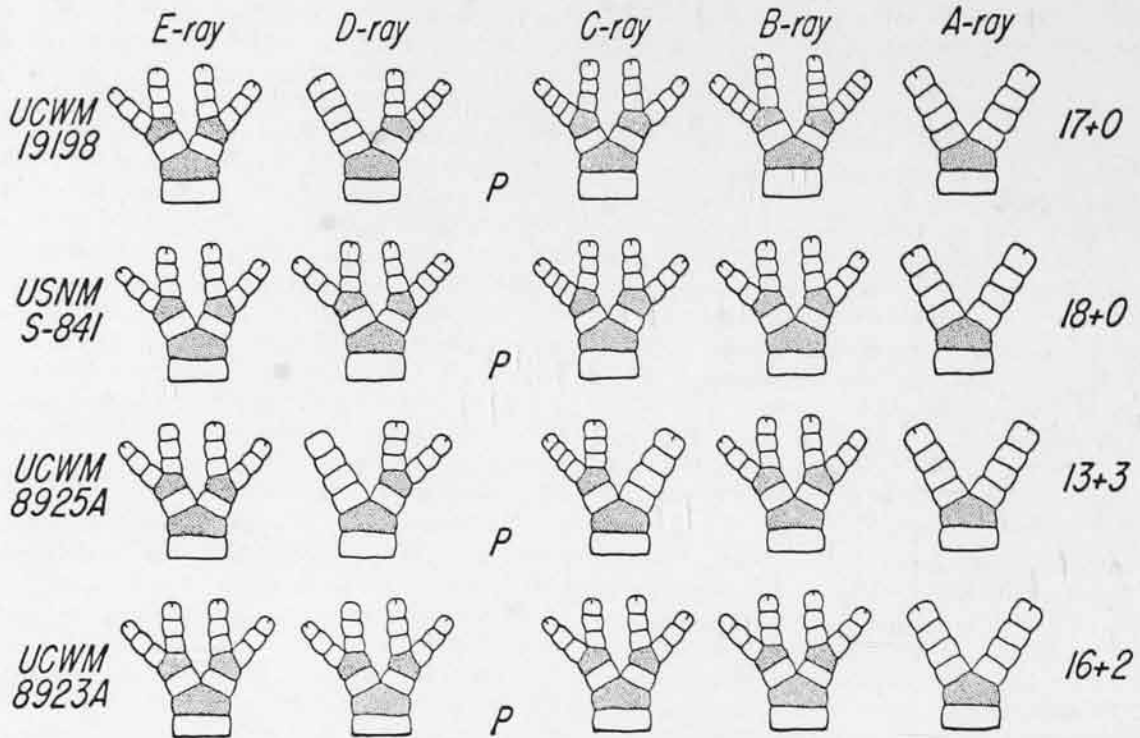


FIGURE 38. Variation in arrangement of fixed-brachials in four specimens of *Dizygocrinus indianaensis*. Plates are spread for clarity; normally they would be in lateral contact. [EXPLANATION: Numbers at right indicate number of paired arms and single arms, respectively, that are supported by most distal fixed brachials. Paired arms are shown by short lines on distal plates. "P" designates posterior; axillary fixed brachials are stippled.]

WACHSMUTH & SPRINGER'S *Dizygocrinus indianaensis* var. *simplex* is considered only a morphological variant of this species. It differs from more typical specimens in the development of 18 single arms, rather than paired arms.

Type. LYON & CASSEDAY'S original specimen is USNM no. S-841. WACHSMUTH & SPRINGER'S figured specimens are USNM no. S-842A,B and their holotype of *Dizygocrinus indianaensis* var. *simplex* is USNM no. S-854.

Occurrence. This species occurs both in the Crawfordsville and Indian Creek crinoid beds in Montgomery County.

Material. Approximately 70 specimens, including plaster casts of the types, were available for my study. Seventeen specimens were selected to be measured.

Dimensions. Measurements made on selected specimens of this species are given on Table 35.

***Dizygocrinus montgomeryensis* (WORTHEN, 1884)
WACHSMUTH & SPRINGER, 1897**

Plate 7, fig. 9, 11, 13; text-fig. 17,2; 19,7

Batocrinus montgomeryensis WORTHEN, 1884, p. 25; 1890, p. 83, pl. 12, fig. 2, 2a.

TABLE 35. Measurements of *Dizygocrinus indianaensis* in mm.

Measurements	Specimens																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dorsal cup height	12.2	12.4	13.0	10.6	11.6	12.3	12.2	13.1	11.6	13.5	12.3	13.4	11.0	7.5	12.9	16.3	11.6
Dorsal cup width	20.2		22.1	14.2	15.9	19.2		17.5		22.0	20.0	21.0	14.0	13.5		23.4	18.5
Basal circllet height	1.8		1.6	1.5		1.4		1.5			1.7		1.4	1.1	1.8	1.0	1.7
Basal circllet width	6.9	7.4	6.6	5.4	4.6	6.4	6.4	6.5	6.4	6.2	7.0	6.6	5.0	5.5	6.3	7.5	6.2
Tegmen height			9.6	8.0						10.1	8.5	9.8	8.9		12.0	10.3	
Arms length	35.7	51.0		36.0	41.0	45.6	42.5	47.5	44.5					26.5			37.5
Number of arms*	18			17	13+3	16+2	17	16	18					18		17	18

* First number refers to pairs of arms, second to single arms (e.g., 16+2=16 pairs plus 2 single arms). 1-3, USNM S841, S842A, S842B; 4-14, UCWM 19198, 8925, 8923 A-I; 15, UC 25008A; 16-17, YPM 1978 A, B.

Dizygocrinus montgomeryensis WACHSMUTH & SPRINGER, 1897, p. 428, pl. 33, fig. 3, 4; pl. 46, fig. 10; LANE, 1963, p. 700.

Batocrinus subconicus WORTHEN, 1884, p. 26; 1890, p. 84, pl. 13, fig. 4. *non Batocrinus gurleyi* ROWLEY & HARE, WACHSMUTH & SPRINGER, 1897.

non Batocrinus sweeti ROWLEY & HARE, WACHSMUTH & SPRINGER, 1897.

non Dizygocrinus montgomeryensis var. *unibrachiatus* WACHSMUTH & SPRINGER, 1897 (= *D. biturbinatus*).

Diagnosis. Dorsal cup bowl-shaped, lower than tegmen; plates smooth; CD interray in contact with tegmen; tegmen high, conical, plates nodose; arms 16, paired and single.

Description. Theca medium-sized to large; sides of dorsal cup gently concave, plates smooth, flat to slightly elevated, faint transverse ridges on RR and small, poorly defined nodes on BrF and iRR₁. BB small, low, slightly wider than column, with raised rim around proximal edge; RR low, wider than high, with distal faces gently concave; iRR 3 to 4; commonly 2 IIBrr, except above each side of IAx in A ray and on anterior side of C and D rays, which have 3 IIBrr; 2 IIIBrr above each IIAxx, rarely 3. Tegmen nearly straight-sided, with flat plates

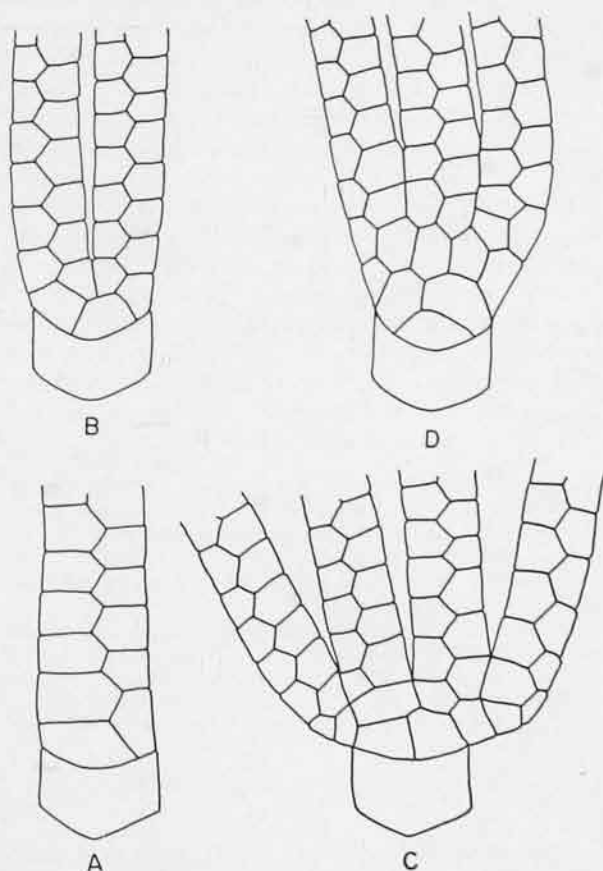


FIGURE 39. Variation of number of arms from a single arm-bearing fixed-brachial and arrangement of free-brachials on specimens of *Dizygocrinus indianensis*.

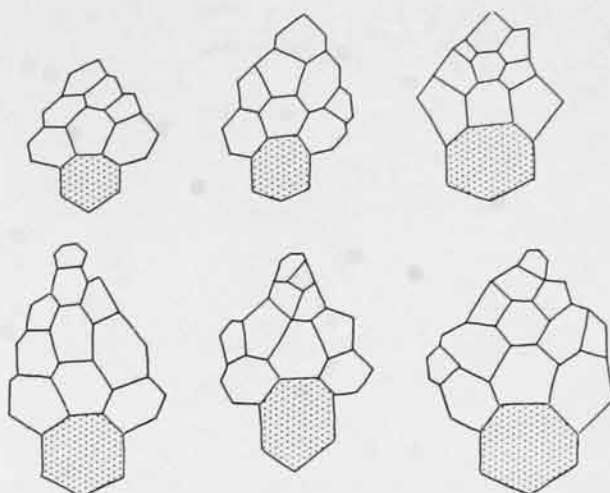


FIGURE 40. Variation in anal plates of *Dizygocrinus indianensis*, X2. [EXPLANATION: Initial anal plate, designated anal X is stippled.]

bearing small- to medium-sized nodes that originate from the central part of each plate; anal tube long, narrow, plates smooth or slightly convex. Arms 16, paired or partly single, 2 in A ray, 3 in C and D rays, 4 in B and E rays.

Remarks. WACHSMUTH & SPRINGER placed *Batocrinus gurleyi* and *B. sweeti* in synonymy of *Dizygocrinus montgomeryensis*, but these species do not have a high conical tegmen with nodes on all plates, which is characteristic of *D. montgomeryensis* and thus should be assigned to *D. biturbinatus* (HALL). *D. montgomeryensis* var. *unibrachiatus* from the Keokuk Limestone, near Keokuk, Iowa, resembles *D. montgomeryensis*, but it lacks paired arms, and except for slight differences in dimensions, represents a typical *D. biturbinatus* as recognized by LANE (1963).

Dizygocrinus montgomeryensis can be distinguished from other forms of the genus occurring at Crawfordsville by its smooth dorsal cup and high conical tegmen. It closely resembles *D. mutabilis* WACHSMUTH & SPRINGER, 1897, from Indian Creek but this species has a more conical dorsal cup and 13 to 14 arm openings.

TABLE 36. Measurements of *Dizygocrinus montgomeryensis* in mm.

Measurements	Specimens		
	IGS X68	IGS 8212	USNM S843
Dorsal cup height	8.2	9.0	9.1
Dorsal cup width	23.5	23.8	17.0
Basal cirlet height	0.8	1.0	0.9
Basal cirlet width	6.1	6.8	4.5
Stem diameter	3.5	4.6	2.8
Tegmen height	12.9	15.0	
Arms length			53.5

Type. WORTHEN's holotype is IGS no. X-68; however, another specimen from the Worthen Collection (IGS no. 8212) is also labelled "Type" (probably a hypotype). WACHSMUTH & SPRINGER's figured specimen (1897, pl. 33, fig. 4) is USNM no. S-843.

Occurrence. This species is known from the Borden beds at Crawfordsville, and WACHSMUTH & SPRINGER's specimen (USNM S-843) is from the Keokuk Limestone of Iowa.

Material. Only specimens listed as types were available for study. Additional specimens were too poorly preserved for detailed study and measurements.

Dimensions. Measurements of specimens available for study are given on Table 36.

[*Dizygocrinus whitei* (WACHSMUTH & SPRINGER, 1881)
WACHSMUTH & SPRINGER 1897]

Remarks. BASSLER & MOODEY (1943, p. 93) report that this species was found at Crawfordsville but it has been cited only from near Canton and Edwardsville in Indiana.

Genus ERETMOCRINUS Lyon & Casseday, 1859

[Miss. (Kinderhook-Keokuk), Iowa, Ill., Ind., Ky., Mo., Tenn.]

LYON & CASSEDAY's original description of *Eretmocrinus* was unsatisfactory and partly incorrect. As a result, much confusion is found in early descriptions of forms belonging to this group of crinoids. HALL (1860, 1861a, 1861b) apparently ignored the name entirely and referred species with typical characters of *Eretmocrinus* to *Actinocrinus*. Others, including original authors, SHUMARD (1866) and ZITTEL (1879), considered *Eretmocrinus* as a subgenus of *Actinocrinus*, and MEEK & WORTHEN referred to it as a subgenus of *Batocrinus*. The name was not recognized, as it should have been, until WACHSMUTH & SPRINGER (1881) re-described *Eretmocrinus* and elevated it to the rank of a genus.

In defining *Eretmocrinus* as a new subgenus LYON & CASSEDAY suggested that the oarlike arms suggest "... a difference of habit in the animal." Apparently they thought that the modified shape of the arms was used for swimming, as well as for their normal functions. The presence of a well-developed stem in all known species unquestionably indicates that these forms were not nektonic.

Detailed study of arm structure of *Eretmocrinus* by LANE (1958), and confirmed in the examination of well-preserved specimens from Crawfordsville, indicates that ambulacral grooves and pinnules on the inner sides of the arms are not present in the expanded portions. Thus, this part of the arms could not have functioned in feeding. LANE suggested, probably correctly, that they formed a continuous roof over the tegmen and prevented fecal matter from dropping onto the tegmen and food grooves.

In general, Keokuk species of *Eretmocrinus* can be distinguished from Burlington forms by a larger, more nodose dorsal cup and tegmen, and by having more arms. *E. commendabilis*, the only known species occurring in the Crawfordsville beds, however, more closely resembles Burlington species.

Eretmocrinus commendabilis MILLER & GURLEY, 1895

Plate 7, fig. 12

Eretmocrinus commendabilis MILLER & GURLEY, 1895, p. 25, pl. 2, fig. 15.

Batocrinus commendabilis S. A. MILLER, 1897a, p. 736.

Diagnosis. Dorsal cup large, plates slightly convex and granulose; BB short, truncated below, expanded into width twice diameter of stem; arms 20, expanding rather abruptly in distal portion into broad spatulate arms.

Description. Dorsal cup twice as wide as long, straight-sided. B cirlet trilobed, thin, notched at distal sutures; RR medium-sized, elevated above interrays; iRR 2, depressed, arched by BrrF; iRR₁ large, followed by smaller pentagonal plate (only one iR observed in available specimen); 1 BrrF consist of 4 IIBrr and 8 IIIBrr in each ray, IIAXx largest plate in ray. Anal X about same in width as RR but slightly higher, followed by 5 Anals. Tegmen and anal tube unknown. Arms 18 or 20, expanding gradually a short distance below wide spatulate portion of arms; commonly coarse nodes or spines on all or part of the free brachials.

Remarks. This species most closely resembles WACHSMUTH & SPRINGER's *Eretmocrinus granuliferus* WACHSMUTH & SPRINGER (1897) from Indian Creek; however, it can be distinguished by its more expanded B cirlet, fewer and more depressed iRR and less gradually expanding arms. It is possible that these two forms should be placed in the same species, but only a single specimen of each was available for study. Both species resemble Burlington forms of *Eretmocrinus*, such as *E. casedayanus* MILLER & GURLEY (1893), more than Keokuk species. In general, the latter species are larger, with more nodose plates and more arms. *E. magnificus* and *E. praegravis* S. A. MILLER 1892, also described from Montgomery County, can be easily distinguished from *E. commendabilis*. The former has 20 to 22 arms, nodose BrrF, and a high nodose tegmen; the latter species has 12 to 15 arms and strongly nodose thecal plates.

Type. MILLER & GURLEY's holotype, and the only specimen available for my study, is UCWM no. 6475. A plaster cast of WACHSMUTH & SPRINGER's *Eretmocrinus granuliferus* was also available for comparative study.

Occurrence. *Eretmocrinus commendabilis* is known only from the Borden beds at Crawfordsville.

Dimensions. The following measurements, in mm., were made on the holotype: height of dorsal cup, 12.8 mm.; width of dorsal cup, 22.4 mm.; width of B cirlet, 13.0 mm.; height of B cirlet, 2.0 mm.; proximal width of arms, 2.5 mm.; maximum width of arms, 12.0 mm.; proximal width of stem, 6.1 mm.

[*Eretmocrinus granuliferus* WACHSMUTH & SPRINGER,
1897]

BASSLER & MOODEY (1943, p. 93, 456) erroneously report this species from the Crawfordsville beds, but specimens have been found only along Indian Creek and near Canton, Indiana.

Genus MACROCRINUS Wachsmuth & Springer, 1897

[Miss. (Burlington, Keokuk), Iowa-Ill.-Ind.-Mo.]

Prior to WACHSMUTH & SPRINGER's monograph on camerate crinoids (1897), species now assigned to *Macrocrinus* were commonly included in *Batocrinus* and *Eretmocrinus*. However, the two latter genera lack the truncate base, nodose RR and iRR, small high dorsal cup and stout anal tube characteristic of *Macrocrinus*. Also, Keokuk species of *Batocrinus* (now referred to *Abatocrinus*) are large, strongly nodose forms.

Macrocrinus is represented in the Crawfordsville beds by a single species, *M. mundulus*, which prior to this study was referred to *M. jucundus*. It was common in the Indiana Creek crinoid beds but rather rare at Crawfordsville.

Macrocrinus mundulus (HALL, 1860) VAN SANT
(n. comb.)

Plate 8, fig. 6, 13

Actinocrinus mundulus HALL, 1860, p. 39.*Actinocrinus similis* HALL, 1860, p. 40.*Actinocrinus lagunculus* HALL, 1860, p. 41.*Batocrinus jucundus* MILLER & GURLEY, 1890, p. 19, pl. 4, fig. 6 (Private publ.); 1890, p. 341, pl. 4, fig. 5, 6.*Batocrinus agnatus* MILLER, 1891, p. 53, pl. 8, fig. 1, 2.*Batocrinus mundulus* WACHSMUTH & SPRINGER, 1897, p. 382, pl. 30, fig. 4, 5.*Macrocrinus lagunculus* WACHSMUTH & SPRINGER, 1897, p. 453, pl. 35, fig. 4; VAN TUYL, 1925, p. 30, pl. 5, fig. 3.*Macrocrinus jucundus* WACHSMUTH & SPRINGER, 1897, p. 451, pl. 4, fig. 15; pl. 30, fig. 13, 14.

Diagnosis. Dorsal cup in the form of a high truncated cone, sides slightly convex, sutures not deeply grooved; RR with rounded transverse nodes; arms short, 16 to 20.

Description. Theca small to medium-sized, width slightly greater than length, dorsal cup higher than tegmen, sutures between plates distinct, truncated at base. BB medium-sized to large, wide, with straight sides, B circlet twice as wide as stem; RR large, with short distinct or indistinct rounded nodes; iRR 1 to 4 in each interray; IIIBrr 2 to 6. Anal X higher than RR, followed by 5 or 6 Anals not in contact with tegmen. Tegmen conical, low, consisting of large plates with small, subcentral nodes; anal tube subcentral, stout, gradually tapering distally, extending beyond arms, plates medium-sized to large, with indistinct nodes. Arms short, thin, 16 to 20.

Remarks. LANE (1958, p. 206) placed many names in synonymy of *Macrocrinus mundulus*, but since this study was unpublished, it has no status nomenclaturally. Comparative study of plaster casts of types with specimens from Crawfordsville, formerly referred to *M. jucundus*, supports LANE's conclusions. The general size, shape, and ornamentation of the dorsal cup are similar and the only apparent difference between the several

species previously described is the number of arm openings to the theca. This is judged only to represent normal morphological variation. Species grouped here in synonymy are all reported from beds of Keokuk age in Illinois, Iowa, and Indiana. *Batocrinus mundulus*, the name-giver to the species, because of priority, has 20 arms and represents the upper extreme in number of arm openings. *B. lagunculus* and *B. agnatus* were named for forms possessing 17 arms, *B. similis* for species with 18 arms, and *B. jucundus* for 16 arms. *B. cantonensis* MILLER & GURLEY (1890), though probably also a synonym, is not included herein because no specimens were available for study.

In general, Keokuk species of *Macrocrinus* differ from Burlington forms in having 16 to 20 arms rather than 12 to 15. However, some overlap exists; for example, the Burlington species *M. verneuilianus* (SHUMARD, 1855) is reported to have 12 to 18 arms, although specimens with greater than 15 arms are rare. This species somewhat resembles *M. mundulus*, but it can be distinguished by having lobed ray areas.

Type. Holotype of *Macrocrinus mundulus* (IGS no. 1848) was not available for study; however, a plaster cast of this specimen (UCWM no. 15774) was examined. In addition, the following types have been examined: plaster cast of the holotype of *Batocrinus agnatus* (USNM no. S-795); hypotype of *M. lagunculus* (USNM no. S-798); MILLER & GURLEY's syntypes of *M. jucundus* (UCWM no. 6259), and a plaster cast of one of WACHSMUTH & SPRINGER's hypotypes (1897, pl. 30, fig. 13).

Occurrence. This widely distributed species has been found in the Keokuk Limestone at Keokuk, Iowa, Nauvoo and Warsaw, Illinois, and the Borden beds at Crawfordsville and Indian Creek.

Material. In addition to the types, the following specimens from Montgomery County, Indiana, were available for study; UCWM no. 8944A,B, UCWM no. 51839A, and NYSM no. 11539.

Dimensions. Measurements made on the specimens available for study are given on Table 37.

TABLE 37. Measurements of *Macrocrinus mundulus* in mm.

Measurements	Specimens								
	1	2	3	4	5	6	7	8	9
Dorsal cup height	9.8	10.8	11.0	10.7	11.5	11.8	11.0	11.6	10.2
Dorsal cup width	12.8	12.0	13.4	14.3	13.7	12.5	11.2	12.0	11.2
Basal circlet height	2.0	2.3	2.4	2.3	2.0	2.0	2.2	2.0	2.0
Basal circlet width	5.0	6.2	6.9	6.4	6.8	6.7	6.4	8.0	5.4
Stem diameter	3.0	3.1	3.0	3.5	3.3	2.9	3.4	3.4	2.9
Tegmen height		8.3						7.4	7.5
Anal tube length	19.0	25.0			26.0	24.0			
Arms length	26.9	34.4		24.0	32.8	32.4	30		
Arms number	15	16	16		16	16	15	17	20

1-3, UCWM 6259 A, B, 5138A; 4, NYSM 11539; 5-6, UCWM 8944 A, B; 7-8, USNM S795, S798; 9, UCWM 15774.

Genus UPEROCRINUS Meek & Worthen, 1865

[Miss. (Burlington, Keokuk), Iowa-Ill.-Ind.-Mo.-Ky.-Tenn.]

MEEK & WORTHEN proposed *Uperocrinus* as a sub-genus of *Actinocrinus*, based on a single species (*Actino-*

crinus pyriformis), but subsequently it was abandoned by them. WACHSMUTH & SPRINGER (1897) and BATHER (1897) recognized the need for grouping species similar to *A. pyriformis*, and proposed *Lobocrinus* and *Hyperocrinus*, respectively. Both considered *Uperocrinus* inappropriate because it had been abandoned by MEEK & WORTHEN in later publications. *Lobocrinus* gained wider acceptance than BATHER's name, probably because the genus is restricted to this continent and American paleontologists tended to follow WACHSMUTH & SPRINGER in matters concerning crinoid studies. *Uperocrinus* and *Lobocrinus* were subsequently used for species having similar characters and not until SPRINGER (1913, p. 196) recognized *Lobocrinus* as a junior synonym was this name discontinued.

Only a single specimen of this genus is known from the Crawfordsville beds, the holotype of MILLER & GURLEY's *Batocrinus marinus*. As discussed below, this species cannot be considered as belonging to *Batocrinus* and is herein judged to be a typical small species of *Uperocrinus*.

Uperocrinus marinus (MILLER & GURLEY, 1890)
VAN SANT (n. comb.)

Plate 8, fig. 3

Batocrinus marinus MILLER & GURLEY, 1890, p. 19, pl. 4, fig. 3, 4 (private publ.); 1890, p. 340.

Lobocrinus spiniferus WACHSMUTH & SPRINGER, 1897, p. 439, pl. 30, fig. 11, 12.

Diagnosis. Theca small, nodes on BB, RR and anal X, all plates granulose; R and B cirlet moderately large for size of dorsal cup; 1 iBr in each ray between IIAXX and above IIBrr₁.

Description. Dorsal cup small, wider than high, sides gently concave, expanding above IAXX; plates slightly convex or flattened. BB rather large, bearing elongate nodes; RR medium-sized to large with single, small transverse nodes; anal X slightly narrower than RR and of about equal height, Anals above arranged 3-3-2; 5 to 6 iRR, commonly 2 in contact with tegmen; 4 IIBrr in all rays, IIAXX followed by 2 large IIIBrr each supporting an arm that is grouped into pairs. Tegmen not visible in known specimens, but judged to be concave and low; anal tube rather long and stout composed of convex, slightly nodose plates, a short distance distal to end of arms 7 to 8 slender spines are developed, 5 to 6 mm. in length arranged almost normal to the longitudinal axis of the anal tube. Arms 20, single, short, only slightly tapering distally and incurved.

Remarks. Presence of grouped rays, iBrr, and the contact of all interrays with the tegmen prohibits assignment of *Uperocrinus marinus* to *Batocrinus* as proposed by MILLER & GURLEY. As previously mentioned, the name *Uperocrinus* was abandoned shortly after MEEK & WORTHEN proposed it and not until WACHSMUTH &

SPRINGER (1897) recognized need for grouping species with characters now considered typical of the genus were these species distinguished from *Batocrinus*.

WACHSMUTH & SPRINGER's *Lobocrinus spiniferus* from Keokuk beds at Indian Creek agrees in all essential characters of dorsal cup and arm structure and probably is a synonym of *Uperocrinus marinus*. Detailed comparison of anal tubes cannot be made since the only known specimen of MILLER & GURLEY's *U. marinus* has the anal tube broken off at the top of the arms.

Type. MILLER & GURLEY's holotype of *Batocrinus marinus* is UCWM no. 6164.

Occurrence. Known only from the Borden beds at Crawfordsville and Indian Creek.

Material. Only the holotype was available for study.

Dimensions. The holotype is distorted so that accurate measurements of many features are impossible; however, the following measurements, in mm., were made: height of dorsal cup, 10.0 mm.; width of B cirlet, 8.0 mm.; width of R cirlet, 11.4 mm.; diameter of stem, 3.0 mm.; approximate length of arms 30.0 mm.

Family COELOCRINIDAE Bather, 1899

[Sil.-Miss.]

Genus AGARICOCRINUS Hall, 1858

[Miss.(Kinderhook, Osage), Iowa-Ill.-Mo.-Ark.-Ind.-Ky.-Tenn.]

Agaricocrinus americanus (ROEMER, 1854)

KEYES, 1894

[emend. KLEM, 1900]

Plate 8, fig. 1; text-fig. 17,3

Amphocracrinus americanus ROEMER, 1854, p. 250, pl. 4, fig. 15a, b.

Agaricocrinus americanus KEYES, 1894, p. 168, pl. 22, fig. 8a,b. WACHSMUTH & SPRINGER, 1897, p. 488, pl. 42, fig. 1a, 2a,b; WOOD, 1909, p. 58, pl. 5, fig. 9.

Agaricocrinus (Amphocracrinus) americanus KLEM, 1900, p. 181, 184. Considered 18 species as junior synonyms.

Agaricocrinus dissimilis MILLER, 1891, p. 665, pl. 8, fig. 11.

non *Agaricocrinus tuberosus* HALL, 1858.

non *Agaricocrinus bullatus* HALL, 1858.

non *Agaricocrinus pentagonus* HALL, 1860 (= *A. bullatus*).

non *Agaricocrinus excavatus* HALL, 1861.

non *Agaricocrinus nodosus* MEEK & WORTHEN, 1869.

non *Agaricocrinus crassus* WETHERBY, 1881.

non *Agaricocrinus elegans* WETHERBY, 1881 (= *A. tuberosus*).

non *Agaricocrinus macadamisi* WORTHEN, 1889 (= *A. tuberosus*).

non *Agaricocrinus nodulosus* WORTHEN, 1889 (= *A. tuberosus*).

non *Agaricocrinus splendens* MILLER & GURLEY, 1890.

non *Agaricocrinus gorbyi* MILLER, 1891 (= *A. splendens*).

non *Agaricocrinus indianensis* MILLER, 1891 (= *A. splendens*).

non *Agaricocrinus arcuata* MILLER & GURLEY, 1895.

non *Agaricocrinus profundus* MILLER & GURLEY, 1895.

non *Agaricocrinus tugurium* MILLER & GURLEY, 1895.

non *Agaricocrinus iowensis* MILLER & GURLEY, 1897 (= *A. profundus*).

non *Agaricocrinus keokukensis* MILLER & GURLEY, 1897 (= *A. profundus*).

Diagnosis. Dorsal cup plates slightly convex, granulose; tegmental plates granulose to pustulose, many highly convex in both Amb and iAmb regions, large; anal X followed by 3 to 5 Anals arranged in 2 series,

these supporting numerous irregularly arranged small plates, which form a large anal protuberance that is depressed laterally.

Description. Theca medium-sized to large, hemispherical to subpyramidal, moderately concave base; all dorsal cup plates slightly convex, those within concavity commonly flatter, sutures distinct. BB small, hidden by stem; RR and IBrr₁ commonly small, IBrr₂ and IIBrr somewhat larger and more convex, in 2 armed-rays arms supported by IIBrr and in 3 and 4 armed-rays posterior arms are borne on IIIBrr; 3 iRR, iR₁ very elongate, narrow, followed by 2 smaller iRR; anal X longer than RR, length greater than width. Tegmen composed of numerous highly convex plates. IAmbb commonly somewhat less convex to almost flat, all plates granulose. Arms 11 to 14, tapering to a point distally; arm facets normal to longitudinal axis or directed slightly upwards.

Remarks. KLEM (1900) considered 18 species to be synonyms of *Agaricocrinus americanus*; however, re-study indicates that many of her junior synonyms represent distinct species based on characters now judged to have significant taxonomic importance. An attempt was made to re-allocate species assigned to *A. americanus* by KLEM, but until a complete review of the genus is undertaken, using actual specimens and not merely descriptions and illustrations, correct placement of several species must remain doubtful.

Only a single specimen of *Agaricocrinus americanus* was found in all material available for study from Crawfordsville. This is the first reported occurrence of this species from this locality, but it has been described previously from equivalent Indian Creek beds. It can be distinguished easily from the more commonly occurring Crawfordsville species, *A. splendens*, by its more granular plates, and large highly convex tegminal plates. Many of these plates are found in both Amb and iAmb regions.

Of particular interest is the fact that the CD pseudoral is separated from other pseudorals and these from each other by much smaller supplementary plates. This feature was one of WACHSMUTH & SPRINGER's diagnostic characters of *Agaricocrinus splendens*. Therefore, isolation of pseudorals cannot be of specific importance, because no regularity exists in their arrangement. It is possible that environment had considerable effect on the development and arrangement of these plates. Thus, when conditions were favorable for growth a few large plates were formed, and during times when conditions were less satisfactory numerous small plates developed.

Type. ROEMER's types were reported by WACHSMUTH & SPRINGER (1897, p. 489) to be in the Mineralogical Museum, Breslau, Poland; however, this could not be confirmed.

Occurrence. *Agaricocrinus americanus* has been reported from the Keokuk Limestone in Clark County, Missouri, Keokuk, Iowa, and numerous localities in western Illinois; Ft. Payne chert at Whites Creek Springs and Livingstone, Tennessee, and from Allen,

Barron, and Metcalf Counties, Kentucky; Edwardsville Formation, Indian Creek and Crawfordsville, Indiana.

Material. Only a single specimen (UCWM no. 8921) was available for study.

Dimensions. The following measurements were made on the specimen available for study: height of theca, 23.4 mm.; height of tegmen, 18.0 mm.; maximum width of tegmen, 29.0 mm.; height of largest arm facet, 6.0 mm.; width of largest arm facet, 5.4 mm.

[*Agaricocrinus nodulosus macadamsi* WORTHEN, 1889]

BASSLER & MOODEY (1943, p. 92) reported that specimens of this species were found at Crawfordsville but these actually came from near Canton and Indian Creek, Indiana.

Agaricocrinus splendens MILLER & GURLEY, 1890

Plate 8, fig. 2, 4; text-fig. 19,3; 20,2,6

Agaricocrinus splendens MILLER & GURLEY, 1890, p. 18, pl. 4, fig. 1, 2 (Private publ.); 1890, p. 340, pl. 4, fig. 1, 2; MILLER, 1892a (adv. pub., 1891) p. 665, pl. 8, fig. 10; WACHSMUTH & SPRINGER, 1897, p. 495, pl. 40, fig. 1a-c.

Agaricocrinus indianensis MILLER, 1892a (adv. pub. 1891), p. 663, pl. 8, fig. 5.

Agaricocrinus gorbyi MILLER, 1892a (adv. pub. 1891), p. 664, pl. 8, fig. 9.

non *Agaricocrinus americanus* (ROEMER), 1854.

Diagnosis. Theca small; dorsal cup plates almost flat, smooth; iR area rather wide and deep; Anals small, distally forming a rounded ridge, which extends from proximal to distal portions of the theca; posterior pseudoral large, highly convex, other pseudorals and radial dome plates distinctly smaller and less convex, remaining tegminal plates small, slightly convex to nearly flat.

Description. Dorsal cup slightly to deeply concave, plates almost flat with moderately distinct suture lines. B cirlet hidden by stem; RR and IBrr rather small; IIBrr commonly long, IIBrr₂ bearing 2 arms in A, B, and E rays, in 3- and 4-armed rays the posterior portion of C and D rays have arms borne on IIIBrr; 3 to 4 iRR; anal X longer than RR, supporting 3 large Anals distally irregular rows of 3 to 5 small plates form a rounded ridge, which is somewhat inflated around anal opening. Tegmen commonly subpyramidal, all plates small except highly convex pseudorals, 4 orals and radial dome plates slightly larger and more convex than other tegminal plates. Arms 12 to 14, stout proximally, tapering uniformly distally; pinnules long.

Remarks. MILLER's *Agaricocrinus gorbyi* and *A. indianensis* agree in all essential features with *A. splendens* and herein are considered to be synonyms. The former species was proposed because it had 13 rather than 12 arms. *A. splendens* can be distinguished from the only other form of this genus occurring in the Crawfordsville beds, *A. americanus*, by its smaller and flatter

tegmenal plates, structure of the *A* series, and almost smooth dorsal cup plates.

Type. MILLER's holotype is UCWM no. 6256. This specimen, originally described from Crawfordsville beds, actually was found at Indian Creek (MILLER, 1891, p. 665). Specimen UC no. 3367, labelled holotype, is not MILLER's type; however, another specimen in the same collection (UC no. 3366) possibly was one of MILLER's original specimens (labelled paratype).

Occurrence. This species has been reported from Keokuk rocks in Washington and Montgomery Counties, Indiana. It was rather abundant at Indian Creek but rare in the Crawfordsville beds.

Material. Eight specimens from Crawfordsville were available for study by me, but only two were suitable for obtaining measurements (IGS no. 28P6, UCWM no. 51836). Several Indian Creek specimens, including the holotype, were measured for comparative purposes (UCWM no. 6256, holotype; UC no. 3367, mislabelled holotype; WC no. 19; USNM no. S-1097A, plaster cast of one of WACHSMUTH & SPRINGER's hypotypes).

Dimensions. Measurements made on specimens available for study are given on Table 38.

TABLE 38. *Measurements of Agaricocrinus splendens in mm.*

Dimensions	Specimens					
	1	2	3*	4*	5*	6*
Crown height						16.5
Dorsal cup width	13.5		18.0	12.0	18.2	21.2
Tegmen height	12.6					11.5
Arms length		59.0	41.3	28.0	50.0	
Arms number	13		12	12	12	12

* Indian Creek specimens. 1, IGS 28P6; 2-3, UCWM 51836, 6256; 4, UC 3367; 5, WC 19; 6, USNM S1097A.

Family DICHOCRINIDAE S. A. Miller, 1889

[Miss.-Perm.]

Genus DICHOCRINUS Münster, 1839

[L.Carb., N.Am.-G.Brit.-Eu.]

The stem and arms of *Dichocrinus* were particularly susceptible to modification without any significant changes occurring in the theca. The stem in most forms is round, without cirri except for distal branching roots, and composed of short columnals or alternating short and long ones arranged in various plans. In other forms cirri were well developed and served their normal function of aiding in attachment. Some highly specialized forms, such as the Burlington species *D. angustus* WHITE (1862), had modified cirri that seemingly functioned partly in protection. This rather bizarre form has numerous whorls of long cirri developed in the proximal 8 cm. of the stem, which completely envelop a small theca and also probably the arms. As discussed below, an extreme modification of the stem occurred in the genus *Camptocrinus*, which has a coiled bilateral stem and a *Dichocrinus*-like theca. This type of stem occurred in unrelated forms and was undoubtedly protective in origin. Early Paleozoic forms possess an inadunate theca, but Mississippian and Permian species have a typical camerate theca.

Arms of *Dichocrinus* vary considerably from the usual 10 to forms with 20 or even 40. Both uniserial and biserial isotomous arms occur, and both types may be present in the same individual. *Paradichocrinus*, a direct descendant from *Dichocrinus*, developed heterotomous arms.

Some forms of *Dichocrinus* had more flexible arms than usual, resulting in a recumbent attitude of the arms when at rest or dead. Recumbent arms developed independently in several camerate families, such as acrocrinids, barrandeocrinids, patelliocrinids, platycrinids, and rhodocrinitids, but are rare in inadunate crinoids (e.g., *Oklahomocrinus*) and unknown in flexible crinoids. The last two groups apparently did not have structural features that could be modified to support such an unusual arm habit. The proof that arms were not accidentally preserved in a recumbent position is shown by the fact that (1) some thecas have distinct grooves resulting from prolonged continuous pressure by the pendent arms, (2) all forms have thick stout pinnules with food grooves exposed to the outer surface, and (3) all individuals within a species commonly exhibit a similar type of arm habit.

In typical camerates, mobility of the arms was limited and no evidence of well-developed muscular articulations has been observed, as in poteriocrinids and several other inadunate families, and post-Paleozoic articulates. BrrF like other plates in the dorsal cup have flat and generally smooth opposing surfaces. More rarely, the surfaces are striated with fine radiating grooves. In both instances the plates were nearly immovable.

The solid tegmen of camerate crinoids had an important function in most forms that had recumbent arms. The tegmen in all species, except those of *Dichocrinus* and *Platycrinites* afforded a firm anchorage for the pendent arms. In some species a slight extension of the tegmen formed an overhanging roof over the dorsal cup, and thus it was impossible for the arms to be raised vertically. Other forms (e.g., *Strotocrinus*) had large extensions of the tegmen that greatly limited upward movement of the arms. Most species, however, had numerous compactly arranged arms and covering plates of adjacent arms were suturally connected for some distance. This modification also prohibited the usual motion of arms, but aided in support of the recumbent ones. Lack of similar anchorage devices in inadunate and flexible crinoids may have been the prime reason why pendent arms are almost unknown in these groups.

In *Dichocrinus* the modified tegmen and suturally connected covering plates do not develop. Study of Brr taking part in the curved portion of the arms indicates that they do not differ in any respect from typical Brr. It must therefore be assumed that recumbent arms as known in *Dichocrinus* species having this character

were merely the result of greater flexibility, caused by more elastic ligaments between individual arm plates. This flexibility may be the reason why most specimens do not have the arms well preserved. In the few specimens that do, no indirect evidence can be found that abnormal amount of elastic tissue occurred between adjacent Brr.

The support or anchorage needed in forms of *Dichocrinus* with pendent arms was furnished by fused IBrr and IIBrr or possibly by development of syzygies. In *D. recurvibrachiatus* several proximal IIIBrr were also fused, thus forming a rigid upright support for the more distal recumbent arms. It is possible, though not confirmed in this study, that sutures between IBrr were also fused. In *D. pentalobus* the BrrF developed a patelloid process as in some Flexibilia, so that the upper plate of a pair has a downward extension or lip that fits into a recess on the upper surface of the plate below. This peculiar structure prevented the proximal portion of the arms from bending backward away from the theca. In flexible crinoids this structure had a similar function, but it was much better developed and not restricted to the proximal Brr.

Dichocrinus ficus CASSEDAY & LYON, 1862

Dichocrinus ficus CASSEDAY & LYON, 1862, p. 24; MEEK & WORTHEN, 1873, p. 502, pl. 14, fig. 5 (non WORTHEN & MEEK, 1875, p. 515, pl. 29, fig. 7; KEYES, 1894 p. 204; WACHSMUTH & SPRINGER, 1897, p. 774, pl. 78, fig. 16a,b.
non *Dichocrinus coxanus* WORTHEN, 1882.
non *Dichocrinus parvulus* MILLER, 1891.

Diagnosis. Theca small, narrow oblong, plates smooth, widest at middle of R cirlet; B cirlet forming obconical portion of dorsal cup, BB about as high as wide; arms 20, commonly pendent.

Description. Dorsal cup narrowing gradually to proximal portion of BB, more rapidly to base of arms. BB truncated at base; RR longer than wide, distal portion deeply excavated for reception of IBrr; R facets narrow, about a third as wide as RR; 2 IBrr, very short, commonly fused, IBr₁ and portion of IBr₂ within R facet; 2 to 3 IIBrr; anal X as large as RR, proximal margin distinctly angular, followed by numerous small Anals forming a small rounded anal protuberance. Arms commonly pendent; pinnules long, stout.

Remarks. In number and pendent position of arms *Dichocrinus ficus* is similar to *D. recurvibrachiatus*, n. sp., which also occurs in the Crawfordsville beds; however, the latter species differs in having a bowl-shaped theca and much wider dorsal cup. The shape of the dorsal cup of *D. ficus* somewhat resembles the Burlington form, *D. pendens*, which has a considerably smaller theca, however, and only 10 arms.

WORTHEN & MEEK (1875) described a specimen from Crawfordsville (actually Indian Creek), which they re-

ferred to *Dichocrinus ficus*, but it has 10 arms and differs significantly in shape of the theca. This specimen is judged to represent a new species and is described below. KEYES (1894) described specimens from Boonville, Missouri, that he referred to *D. ficus*; however, his description was generalized and not accompanied by an illustration, and thus it is impossible to judge if his specimens were correctly assigned. He considered WORTHEN's *D. coxanus* and MILLER's *D. parvulus* as synonyms of *D. ficus*, but these are entirely different and distinct species. *D. coxanus* differs in having a considerably smaller theca, more narrowly pointed base, small irregular ridges on the surface of all cup plates, and 10 arms. MILLER's species has slightly convex plates with a granular surface, with R facets with only a slight depression for reception of IBrr, and 10 arms. It is possible that KEYES' specimens represented one of these 10-armed forms.

Type. CASSEDAY & LYON's holotype is USNM no. S-1500, and the hypotype used by WACHSMUTH & SPRINGER in their monograph on camerate crinoids is USNM no. S-1499. MEEK & WORTHEN's hypotype is IGS (ISM) no. 2399.

Occurrence. This species has been reported from Keokuk and equivalent rocks at Crawfordsville and Hardin County, Kentucky. KEYES questionably identified specimens from ?Warsaw rocks at Booneville, Missouri. Judging from the number of specimens available for study, this species was extremely rare at Crawfordsville.

Material. Only MEEK & WORTHEN's hypotype was available for study. In addition, plaster casts of the holotype and WACHSMUTH & SPRINGER's hypotype were examined.

Dimensions. Measurements made on specimens of this species are given on Table 39.

TABLE 39. Measurements of *Dichocrinus ficus* in mm.

Measurements	Specimens		
	USNM S1500	USNM S1499	IGS 2399
Dorsal cup height	12.1	11.4	12.8
Dorsal cup width	9.4	9.2	8.9
Basals height	6.5	5.7	6.2
Proximal part			
basals width	2.0	2.4	2.8
Radial to arm			
facet height	7.0	11.0	6.4
Radial width			5.2

Dichocrinus recurvibrachiatus VAN SANT, n.sp.

Plate 8, fig. 16

Diagnosis. Dorsal cup medium-sized, wide, bowl-shaped, plates smooth; arms 20, recurving into pendent position; distal Brr rectangular.

Description. Dorsal cup almost straight-sided above B cirlet. BB low, evenly bowl-shaped, truncated only slightly for stem impression; RR about as wide as long, R facet in distal one-fourth of plate, almost a third as wide as RR; 2 IBrr, very small, commonly fused; IIBrr₂ axillary; proximal IIIBrr moderately large, rounded, IIIBrr₃₋₄ partly or entirely fused. Anals and tegmen un-

known. Arms 20, uniserial, long, pendent, recurving above III Brr_{4-5} ; distal Brr becoming longer and less rounded, each bearing a long, stout, flattened pinnule; pinnules beginning on II Brr_1 or II Ax . Stem round, every 3 or 4 columnals separated by a thin, expanded stellate-stem ossicle.

Remarks. *Dichocrinus recurvibrachiatus* most closely resembles *D. pendens* WACHSMUTH & SPRINGER (1897) from the upper Burlington Limestone of Iowa in general shape of theca and pendent position of arms. However, the latter species differs in having a large theca, wide R facets, and alternating cuneate Brr. *D. ficus*, which is associated with *D. recurvibrachiatus* in the Crawfordsville beds, can be distinguished easily by its small, narrow oblong dorsal cup.

The arm structure of this species differs from other known species in several important and interesting aspects. Unlike *Dichocrinus pendens*, the proximal Brr in *D. recurvibrachiatus* are fused, and thus IBrr , II Brr , and III Brr_{1-4} form a rigid upright support for pendent portion of arms. Several other species have fused IBrr and II Brr and these undoubtedly served as a similar support. Fusion of proximal Brr or development of syzygies was necessary in forms with pendent arms because the distal portions of arms are much more flexible than more typical arms of camerate crinoids. As discussed above, muscular or even highly-developed ligamentous articulations are unknown in most camerates, and thus if arms became rather flexible, as in certain species of *Dichocrinus*, a modified support probably developed. It is more reasonable to assume that in these forms a fusion of lower Brr plates occurred rather than development of specialized articulations. The nature of the R facet and facets of the Brr in *D. recurvibrachiatus* or any other species of this genus does not suggest that well-developed articulations occurred.

Pinnules of *Dichocrinus recurvibrachiatus* do not differ significantly in size, shape, and structure from those of other species with recumbent arms (e.g., *D. pendens*). It is interesting, however, that in this species pinnules first appear on II Brr so that these plates support the II Ax and a pinnule. Pinnules on II Brr and III Brr_{1-4} were not observed on the specimen available for study; however, they undoubtedly also existed on these plates.

Type. The holotype and only known specimen of this species is UCWM no. 51832.

Occurrence. Known only from Borden beds at Crawfordsville.

Dimensions. The following measurements were made on the holotype: height of dorsal cup, 10.5 mm.; width of dorsal cup, 10.0 mm.; width of distal portion of B circle, 8.5 mm.; diameter of stem, 1.8 mm.; height of RR, 6.8 mm.; width of R facet, 1.8 mm.; length of preserved portion of arms (along curvature), 33.2 mm.

Dichocrinus sp.

Plate 7, fig. 1

Dichocrinus ficus WORTHEN & MEEK, 1875, p. 515, pl. 29, fig. 7.

WORTHEN & MEEK described a single specimen (UCWM no. 8942) of *Dichocrinus* from Indian Creek (not Crawfordsville as they stated), which was referred to *D. ficus*. It differs from this species in having 10, rather than 20, arms and in general shape of theca, and unquestionably was not properly assigned. Because the dorsal cup is rather badly crushed, and only represented by a single specimen, it is not re-named herein. Curiously, the original authors thought that the narrow R as shown in their illustration was the anal plate and that it supported 2 IBrr and arms. Examination of the specimen, however, indicates that this is a R and its narrowness is the result of adjacent RR being forced over this plate when the specimen was crushed.

Genus CAMPTOCRINUS Wachsmuth & Springer, 1897

[L. Carb., N. Am.-Scot.; Perm., Timor-USSR]

Development of a coiled bilateral stem distinguishes *Camptocrinus* from all other camerate crinoids. This peculiar type of stem is also found in otherwise unrelated genera of inadunate (e.g., *Myelodactylus*, *Herpetocrinus*) and flexible (e.g., *Ammonicrinus*) crinoids and in both subclasses the stem exhibits a similar type of organization. In most specimens the proximal portion of the stem is composed of very short and uniform ossicles, which do not bear cirri. Distally the stem becomes flattened or concave on the inner side and columnals become elliptical or crescentic in cross section. The cirri instead of occurring as whorls arranged completely around the stem, as in typical cirrus-bearing crinoids, are commonly restricted to two rows at or near margins of the flattened sides. The crown is typically bent back upon the stem and completely enclosed by it and covered by well-developed cirri. The development of such a modified stem was undoubtedly protective in origin, but judging from the comparatively few known species and specimens, it was not a particularly satisfactory modification and was never widely adopted. Crowns did not undergo significant changes throughout the range of genera and most changes that did occur took place in the stems. Commonly, many parallel changes can be traced independently in Silurian and Devonian forms of *Myelodactylus* and *Ammonicrinus* and Mississippian forms of *Camptocrinus*.

Camptocrinus possesses a *Dichocrinus*-like crown, which did not change significantly from Burlington to Chesteran time. The stem, although commonly appearing similar to forms of *Myelodactylus*, furnishes good specific characters, and has been used almost exclusively in classifying various species. Beyond the proximal round portion of the stem ossicles become elliptical and of different lengths. The marginal cirri arise from paired nodals, which are separated from each other by one to four internodals.

Several variations from the typical *Camptocrinus*-type

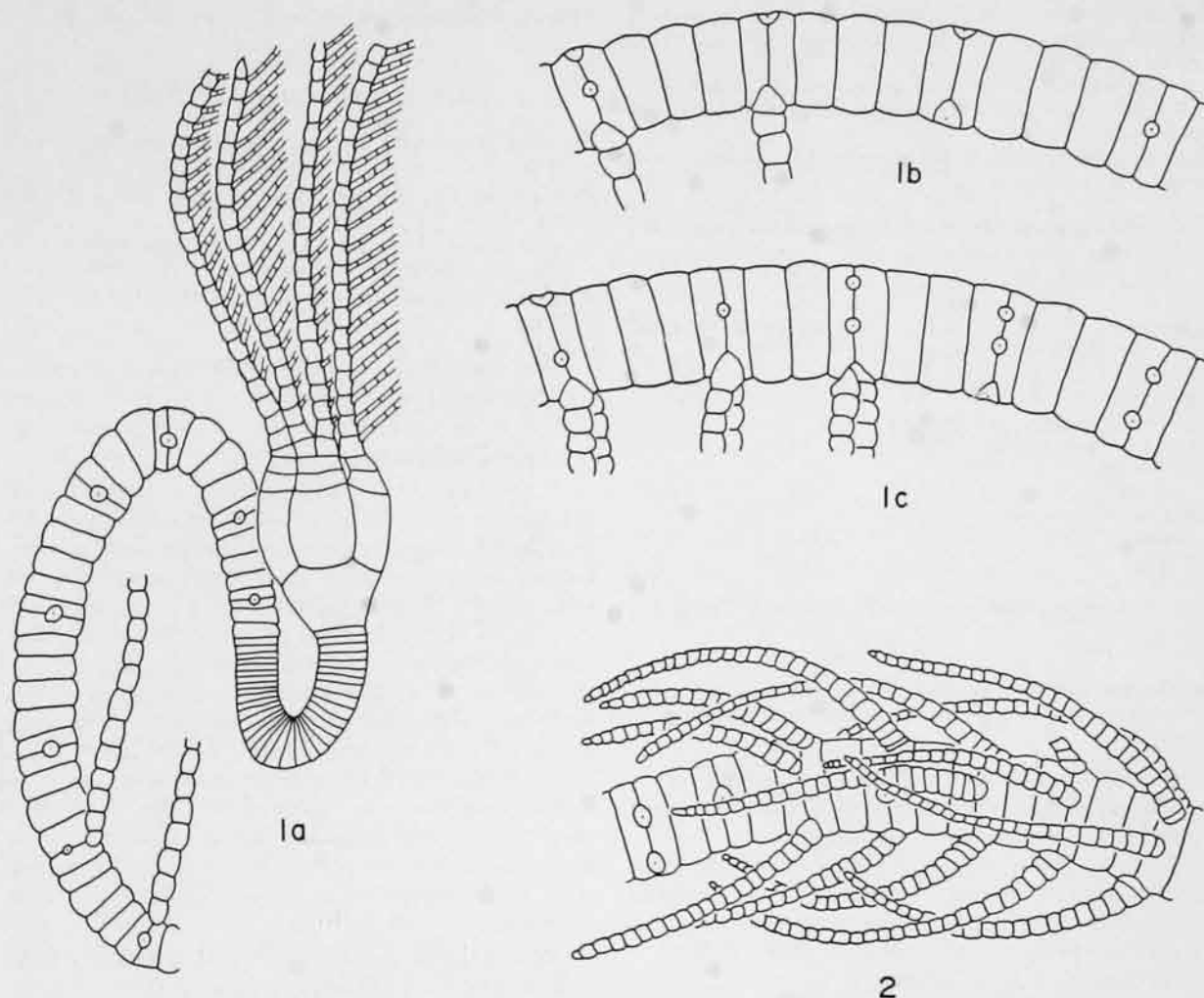


FIGURE 41. 1a. Diagrammatic representation of the crown and portions of the stem of *Camptocrinus crawfordsvillensis*. Note *Dichocrinus*-like crown and lack of cirri in the proximal portion of stem, X3.—1b,c. Portion of stem in two specimens representing this species, X5.—2. Portion of stem in *C. pleniccirrus* showing development of cirri whorls completely around stem, distal toward left, X5 (after Springer, 1926).

plan (Fig. 41) are illustrated by the Crawfordsville species, and these indicate a tendency of the species to resume the typical arrangement of cirri in whorls around the stem. In *C. crawfordsvillensis* small rudimentary cirri consisting of only one or several cirrals occur, in addition to the long, well-developed marginal ones (Fig. 41,1). *C. pleniccirrus* possesses well-developed cirri in whorls of 5 around the stem, and the ossicles are only slightly elliptical (Fig. 41,2).

***Camptocrinus crawfordsvillensis* SPRINGER, 1926**

Text-fig. 41

Camptocrinus crawfordsvillensis SPRINGER, 1926, p. 30, pl. 8, fig. 1-3c.

Dichocrinus (Camptocrinus) myelodactylus WACHSMUTH & SPRINGER, 1897, p. 779, pl. 75, fig. 1 (non fig. 2a,b).

Diagnosis. Stem coil open, not closely enveloping crown; cirri commonly doubled, rarely single or tripled, arising from a pair of short nodals; marginal cirri long, rather stout, composed of 20 to 25 cirrals; towards distal end of stem remnants of smaller secondary cirri formed at back of some columnals, extreme distal portion of stem round; commonly 2 or 3 internodals interposed between pair of nodals, rarely 4.

Remarks. Only three specimens of this species are known (USNM no. 1518A-C) and nothing significant can be added to SPRINGER's original descriptions. *Camptocrinus crawfordsvillensis* differs from the other Crawfordsville species, described below and *C. myelodactylus* from Indian Creek, in having two or more internodals and in possessing marginal rows of long cirri.

Type. SPRINGER's syntypes (USNM no. 1518A-C) represent all known specimens of this form. Specimen USNM no. 1518C is herein selected as lectotype.

Occurrence. Known only from Borden beds at Crawfordsville.

Material. Plaster casts of the lectotype and paratypes were available for study.

Dimensions. Approximate measurements of the specimens available for study are given on Table 40.

TABLE 40. *Measurements of Camptocrinus crawfordsvillensis in mm.*

Measurements	Specimens		
	USNM 1518A	USNM 1518B	USNM 1518C
Dorsal cup height	5.0		6.0
Dorsal cup width	5.2		6.2
Arms length	17.2		21.2
Diameter stem proximal ..	2.0	1.8	1.4
Stem diameter			
maximum	2.6	4.0	2.6
Cirri maximum preserved			
length	12.3	14.3	17.4

Camptocrinus plenicirrus SPRINGER, 1926

Text-fig. 41,2

Camptocrinus plenicirrus SPRINGER, 1926, p. 30, pl. 7, fig. 6, 6a.
Camptocrinus plenicirrus (misspelling) BASSLER & MOODEY, 1943, p. 355.

Diagnosis. A small species with 5 cirri developed around each pair of nodals; paired short nodals interposed between single internodals.

Remarks. No specimens of *Camptocrinus plenicirrus* were available for my study. In arrangement of columnals *C. plenicirrus* is similar to *C. myelodactylus* from Indian Creek, but cirri are distributed on a different plan. It differs from *C. crawfordsvillensis* in having single internodals, rather than 2 or more and in the short, tapering cirri that are not arranged in marginal rows.

Type. The only known specimen of this species is USNM no. 1522.

Occurrence. Known only from Borden beds at Crawfordsville.

Genus PARADICHOCHRINUS Springer, 1926

[Miss. (Keokuk), Ind.]

Only two species have been assigned to this genus, and both are restricted to Borden rocks at Crawfordsville and Indian Creek. In all known specimens the heterotomous arm branching is developed on a similar plan, with the ray dividing into two main branches, from which 3 to 5 subordinate branches are given off to the outside of the dichotomy (see pl. 8, fig. 7, 11). The Crawfordsville species, *Paradichocrinus polydactylus*, is represented by more than 100 well-preserved specimens and forms a conspicuous aspect of the camerate fauna at this locality. At Indian Creek specimens of *D. planus* were rare and only 5 specimens are known.

Paradichocrinus polydactylus (CASSEDAY & LYON, 1862) SPRINGER, 1926

Plate 8, fig. 7, 11; text-fig. 17,6,7; 19,5,6,8

Dichocrinus polydactylus CASSEDAY & LYON, 1862, p. 18; WACHSMUTH & SPRINGER, 1897, p. 756, pl. 77, fig. 1a,b.

Paradichocrinus polydactylus SPRINGER, 1926, p. 51, pl. 10, fig. 5, 6.

Dichocrinus expansus MEEK & WORTHEN, 1868b, p. 343; 1873, p. 500, pl. 14, fig. 1 (non DE KONINCK & LE HON, 1854).

Dichocrinus stelliformis MEEK & WORTHEN, 1868b, p. 344; 1873, p. 502.

Diagnosis. Dorsal cup plates thin, with small irregular nodes commonly arranged in vertical rows; tegmen high, 6 to 10 arms in each ray, uniserial portion with well-developed ligamentary fossa.

Description. Dorsal cup widening gradually along BB, abruptly to distal edge of RR, plates thin, convex. BB large, nodes commonly coalescing near proximal portion, forming rim around lower margin; RR becoming much wider distally, R facet bounded by a large, thickened rim; longer and wider than RR, strongly convex. Tegmen higher than dorsal cup, plates large, slightly convex, commonly with a small subcentral node; Ambb well developed; small anal protuberance. Arms exotomous, slightly tapering distally; 2 IBrr, short, commonly fused; 2 to 3 IIBrr; most commonly 4 arms in each half ray, borne on outside of the IIBr₂, IIIBr₂, and above IVBr₂; arms becoming biserial above the fourth or fifth individual arm plate; pinnules numerous, moderately long. Stem round, nodals slightly wider than internodals.

Remarks. *Paradichocrinus polydactylus* differs from *P. planus* SPRINGER, 1926, the only other known species, in having nodose cup plates, rather than smooth ones, and a high tegmen. It differs also in commonly having fewer arms. MEEK & WORTHEN's *Dichocrinus expansus* differs only in possessing 6 arms in each ray, rather than more typical 8 or 10.

In the description of *Dichocrinus expansus* MEEK & WORTHEN suggested that considerable variation exists in ornamentation exhibited in this species and some specimens show a tendency for the nodes to coalesce into definite ridges. For these specimens they proposed the name *D. stelliformis*, but stated "It is possible this would be found to be a distinct species, if we could examine a specimen showing the arm. If so, it may be called. . . ." Strict interpretation of the rules of nomenclature would make this species valid even though the authors only suggested the name and did not propose it formally. They thought their specimens were distinct even though no arms were preserved, and the authors described their specimens. In short, they proposed and described a valid new species even though it was named provisionally.

Examination of several specimens having ornamentation described by MEEK & WORTHEN indicates that these represent only one extreme within the species, and thus *D. stelliformis* is considered a junior synonym.

Type. WACHSMUTH & SPRINGER's holotype is USNM no. S-1575 and MEEK & WORTHEN's figured specimens of *D. expansus* are IGS (ISM) no. 1815, 1815.

Occurrence. Known only from Borden beds at Crawfordsville.

Material. Approximately 30 specimens of this species were available for my study, including MEEK & WORTHEN's hypotypes and a plaster cast of the holotype. A majority of the specimens could not be adequately measured because they were either badly crushed, owing largely to the thinness of plates, or only a portion of the crown was preserved. SPRINGER (1920, p. 51) reported that in his collection he had over 50 well-preserved crowns of this species. Specimens selected for measurements include the following: plaster cast of USNM no. S-1575 (holotype); IGS (ISM) nos. 1814, 1815 (hypotypes of *D. expansus*); UCWM nos. 26480, 8918A,B; YPM nos. 6447A,B,C; 22754A,B; UC nos. 25035A,B.

Dimensions. Measurements made on selected specimens available for study are given on Table 41.

Suborder GLYPTOCRININA Moore, 1952

[Ord.-Perm.]

Family PLATYCRINITIDAE Austin & Austin, 1842 (Bassler, 1938)

[Dev.-Perm.]

[*nom. subst.* BASSLER, 1938, p. 23 (*pro* Platycrinidae AUSTIN & AUSTIN, 1843, p. 199, *nom. correct. pro* family Platycrinoidae AUSTIN & AUSTIN, 1842, p. 109)]

Genus PLATYCRINITES J. S. Miller, 1821

[Dev.-Perm., N.Am.-G.Brit.-Eu.-Timor]

Although *Platycrinites* is represented in the Crawfordsville beds by a single species, in numbers of individuals, it was probably one of the most abundant forms present. In addition the characteristic elliptical and twisted stem ossicles, which are connected by synarthrial articulations, form an important aspect of crinoidal fragments found in the matrix. Presence of very abundant *Platyceras* in these beds is explainable, in part, by the large numbers of specimens of *Platycrinites*. The

nearly flat tegmen and widely spaced arms provided an excellent attachment for these coprophagous mollusks.

Platycrinites hemisphericus (MEEK & WORTHEN, 1865) BASSLER & MOODEY, 1943

Plate 8, fig. 9, 17; text-fig. 17-4; 19-1,2

Platycrinus hemisphericus MEEK & WORTHEN, 1865b, p. 162; 1868a, p. 511, pl. 20, fig. 2a,b; 1873, p. 506, pl. 16, fig. A-C; WHITE, 1882, p. 368, pl. 41, fig. 1; WACHSMUTH & SPRINGER, 1897, p. 703, pl. 66, fig. 1a-d.

Platycrinites hemisphericus BASSLER & MOODEY, 1943, p. 621.

Diagnosis. Dorsal cup bowl-shaped, nearly twice as wide as high; plates covered with rather large, rounded nodes, commonly arranged in rows, with smaller, irregularly arranged nodes; 6 to 8 arms in each ray.

Description. Theca subglobose, large in proportion to arms; base slightly excavated for reception of stem; sutures mostly distinct, not deeply grooved. Basal sutures indistinct; RR subquadrangular, wider than high, moderately expanding in width distally, sides of distal portion sloping proximally except in CD interray where they form a broad, deep notch; R facet horseshoe-shaped, about one-third of height and width of plates, directed obliquely upward, face concave, smooth, distal portion deeply notched; IBr, very small, nearly triangular, axillary; 2 IIBr, free; anal X very small, pentagonal. Tegmen somewhat hemispherical, nearly flat but slightly bulging at sides; plates large, nodose, nearly uniform in size; OO commonly larger; anus low, near periphery of tegmen. Arms 6 to 8 in each ray, branching alternately, tapering uniformly to point distally, commonly uniserial in proximal portion, composed of 5 to 8 cuneate Brr above dichotom, distally becoming biserial; median portion of proximal Brr with small distinct fossa and serrated outer margins, distal Brr faces almost flat, with finely serrated margins; pinnules long, thin. Stem moderately large, circular in extreme proximal portion, elliptical throughout most of length and distally; cirri short and circular.

TABLE 41. Measurements of *Paradichocrinus polydactylus* in mm.

Measurements	Specimens												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Dorsal cup height	20.9	18.0		16.8	15.3		14.4	16.0	19.0	12.4	12.8		
Dorsal cup width	33.6				22.0			23.0			19.6		
Basals height	9.3	7.5	8.3	8.3	8.2		6.7	8.0	8.0		5.2	5.4	5.4
Radials height	14.0	8.0	8.0	8.5	8.3		8.7	9.0	11.0	9.0	7.3	12.2	8.0
Radial facet width	4.4	3.8	3.7	3.3	3.0	3.4	2.8	2.9	2.7	3.8	2.5	3.0	2.4
Tegmen height								26.5	20.2				
Arms length	74.4			81.0	72.6	69.0	60.0			51.0			50.8
Arms number per ray	8	6		8-9	8	8-9	8-9	8	8	8-9	8	8	8
Stem diameter	5.0	2.5	3.0	5.1	3.9		3.0	5.0	4.1	3.7	3.4		

1, USNM S1575; 2-3, IGS 1814, 1815; 4-6, UCWM 26480, 8918 A, B; 7-11, YPM 6447 A-C, 22754 A, B; 12-13, UC 25035 A, B.

Remarks. In shape of theca, type of ornamentation, and arm structure *Platycrinites hemisphericus* more closely resembles lower Burlington forms than those found in rocks of Keokuk age. The older species [e.g., *P. pocilliformis* (HALL, 1958), *P. spinifer* (WACHSMUTH & SPRINGER, 1897), *P. verrucosus* (WHITE, 1865), *P. yandelli* (OWEN & SHUMARD, 1850)] are characterized by a more or less cup-shaped theca that widens slightly, but uniformly, distally, distinct and well-developed nodes, and arms of moderate size. *P. hemisphericus* differs from these forms, in having a large somewhat more bowl-shaped dorsal cup, proportionally less robust arms, and a low, nearly flat tegmen. It also can be distinguished by its rather large, rounded, prominent nodes. Indian Creek species closely resemble upper Burlington and other Keokuk species and can be easily distinguished from *P. hemisphericus*. HALL's *P. brevinodus* (1861) is a rather small species with low dorsal cup, in which the sides are nearly straight and the base flat. It also has low, angular radiating ridges on the RR and 4 to 6 arms in each ray. *P. saffordi* (HALL, 1858) is characterized by its large, oblong theca, which is covered by numerous, coarse nodes that are commonly arranged in transverse rows following the margins of the cup plates. Also the R facets are extremely small and confined to the distal portion of the RR.

Type. MEEK & WORTHEN's holotype is IGS (ISM) no. 1818A.

Occurrence. *Platycrinites hemisphericus* was extremely abundant in the Crawfordsville beds. It has also been reported from rocks of Keokuk age at Keokuk, Iowa, but is relatively rare at this locality.

Material. More than 100 specimens of this species were available for study, including the holotype and several hypotypes. Fifteen mature specimens were selected at random for measurements.

Dimensions. Measurements made on the selected specimens are given on Table 42.

APPENDIX A

TERMINOLOGY AND ABBREVIATIONS USED

The numerous discrete parts of crinoids necessitates an elaborate terminology in order to describe and dis-

cuss these organisms adequately. Early workers employed widely different names, commonly for the same skeletal elements, and it was not until BATHER (1900) wrote his treatise on both fossil and living crinoids that a standard system of terms was widely adopted. MOORE & LAUDON (1941, 1943) revised BATHER's system of designating structural elements. MOORE (1950, 1952) further revised the terminology and symbols for morphological features and these papers have served as a standard for recent crinoid investigations. Two important additional studies by MOORE (1962a, b) have discussed terminology of the specialized inadunates, the calceocrinds, and ray structures of certain inadunate crinoids. The terminology used in this study accords with that proposed by MOORE (1950-62) and these terms are not re-defined here; however, slight modifications of terminology to be adopted in the crinoid volume of the *Treatise on Invertebrate Paleontology* are defined below. As this section of the *Treatise* is not yet completed and final agreement on terms and symbols has not been decided, some abbreviations and designation for plates employed in my study may undergo further revision.

ORIENTATION

For purposes of description and illustration crinoid crowns are oriented with the arms directed upward. Specimens in which the arms are not preserved (or in a few forms that were armless during life) the dorsal cups are similarly oriented with the ventral (oral) side placed upward. Most crinoids lack perfect pentamerous symmetry and one interray area is noticeably different from other interray regions. It may contain supplementary plates, be much larger or support an anal tube. This region by convention is designated posterior and the ray opposite is then defined as the anterior ray. When a dorsal cup is viewed orientated in the normal living condition the anterior ray is held away from the observer and left and right can be differentiated directly (e.g., left-posterior, right-anterior, etc.); however, when viewing a specimen from the dorsal (aboral) side it is necessary to place the anterior ray toward the observer, if consistency of left and right directions are to be main-

TABLE 42. Measurements of *Platycrinites hemisphericus* in mm.

Measurements	Specimens														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Dorsal cup height	13.4	9.0	11.4	16.5	15.0	15.8	14.6	15.0	12.4	8.5	11.7	13.0	17.0	14.0	20.8
Dorsal cup width	26.6	15.6		22.0		23.0	24.0	25.0	18.1	12.3	19.0	14.0	24.5		28.7
Basal circlet width	14.4	10.0		9.2			15.3	12.2	11.5	7.3	13.0	11.9	15.5	15.0	18.0
Radial height	8.7	7.4	7.2	12.2	11.9	13.0	14.0	12.3	10.0	5.6	7.0	8.5	11.8		14.2
Radial width	15.6	8.2	9.3		15.5		14.6		11.0	7.3	10.0	14.0	14.0	13.2	15.8
Arm facet width	4.6	3.6	4.0	4.3	5.0	5.4	6.0		5.0	3.4	4.0	4.0	5.1		6.8
Arms length		32.2	47.0	48.8		51.0	40.0	51.0	39.0	29.3	45.3	48.0	52.0	47.9	56.2

1, IGS 1818A; 2-3, IDG 10120A, E1220A; 4-5, NYSM 11540, 11541; 6-15, UCWM 3214 A, B, 8919 A-E, 51850, 15235, 51851.

tained. This system has been used almost without exception in previous studies but the unnatural designation of rays and interrays has caused many unnatural arrangements of illustrations and description.

A much more usable method of designating rays and interrays was proposed by CARPENTER (1885) and it has the advantage of being concise and easy to use regardless of position of observer or orientation of the specimen. This system was used in my study and it has been adopted in the *Treatise on Invertebrate Paleontology*. Undoubtedly it will become the standard method for orientation followed by future crinoid students. According to the CARPENTER system the anterior ray (as defined above) is designated by the letter *A* and other rays are distinguished as *B*, *C*, *D*, and *E* rays in a clockwise direction when viewing the ventral (oral) side. Adjoining interray areas are designated by combining the terms of adjacent rays. Thus, the posterior interray is termed the *CD* interray, the interray between the *E* and *A* rays is designated *EA* interray, etc. For the sake of uniformity, views of the dorsal side are similarly designated but in a counter-clockwise succession.

NONSTANDARDIZED TERMS AND ABBREVIATION USED IN THIS STUDY¹

Anal (Anal, Anals). Any plate of *CD* interray, mostly confined to dorsal cup but excluding fixed-pinnulars and among inadunate and flexible crinoids including plates of *C* ray other than radials, radianals, brachials, aniradials, and pinnulars. This term is used in the present study mostly to distinguish plates in *CD* interray of camerates immediately following first anal plate designated primanal or anal X (see anal X).

anal X (anal X). Special anal plate in inadunate, flexible, and camerate crinoids typically located between *CD* radials (posterior) distal to and upward left of radianal, if present. Previously the term tergal was used to designate this plate of camerate crinoids, but studies by MOORE (not yet published) suggest that the first anal plates in all Paleozoic forms are homologous, and thus should be similarly designated.

armlet. Bifurcating or nonbifurcating minor branch of arms, differing from pinnules in less regular occurrence and in some forms by presence of supplementary branches termed ramules.

brachial (Br, Brr). Any ray plate, exclusive of pinnulars, beyond radials. In camerates this term applies to only those plates that are free above the dorsal cup (free-brachials). See fixed- and free-brachial.

fixed-brachial (BrF, BrrF). Any ray plate except pinnulars and radials incorporated into dorsal cup. These plates were previously called cup-brachials.

free-brachial (Br, Brr). Any ray plate except pinnulars not included in dorsal cup.

primanal (anal X). Most proximal anal plate. This term has been used by some authors instead of tergal plate in camerates (see anal X).

ramule (ramule, ramules). Supplementary small arm-like series of plates branching off of an armlet.

subaxillary (SAX, SAxx). Axillary brachial that gives rise to an arm branch and one bearing an armlet; opposed to normal axillary plate, which is a brachial supporting two arm branches.

theca (theca). Crinoid skeleton exclusive of column and free arms. Previously the term calyx was used instead of this term. Some authors have used calyx as an equivalent to dorsal cup.

MEASUREMENTS USED

Measurements are important elements of taxonomic descriptions because they provide both an idea of the size of specimens and a basis for comparison of sizes of various structures between individuals of the same species. No standard method of designating measurements has been generally adopted in crinoid studies, and thus it is important to provide definitions of measurements used. Measurements of most of the species occurring at Crawfordsville were not previously given in taxonomic descriptions and so little information pertaining to size of various circlets of plates and structures was available prior to the present study. Because the same plates commonly vary slightly in size, in this study the largest plate (in a series) was measured. It was impossible to measure the same plates on all specimens (e.g., *C* radial, *BC* basal, etc.) because most specimens were not completely separated from the matrix. Thus, only one or two rays are commonly exposed.

APPENDIX B

CHECK-LIST OF NAMES APPLIED TO CRAWFORDSVILLE CRINOIDS

Because many specimens in various collections are now incorrectly labelled with names considered to be synonyms, it is desirable to provide some system that will enable the names to be corrected readily. The following alphabetical list includes all names that have been applied to Crawfordsville crinoid species, except those misidentified or used with wrong combinations of generic and trivial names. Valid species are marked with an asterisk and synonyms are unmarked; however, number indicating valid name is included in parentheses at end of each citation.

1. **Abatocrinus grandis* (LYON & CASSEDAY), 1859.
2. **Abrotocrinus coreyi* (MEEK & WORTHEN), 1869.
3. *A. cymosus* MILLER & GURLEY, 1890 (=4).
4. **A. unicus* (HALL), 1861.
5. **Actinocrinites gibsoni* (MILLER & GURLEY), 1894.
6. *A. urna* TROOST, 1849 (=1).
7. *Actinocrinus grandis* LYON & CASSEDAY, 1859 (=1).
8. *A. indianaensis* LYON & CASSEDAY, 1860 (=1).
9. *A. lagunculus* HALL, 1860 (=105).
10. *A. multiramosus* WACHSMUTH & SPRINGER, 1897 (=5).
11. *A. mundulus* HALL, 1860 (=105).
12. *A. similis* HALL, 1860 (=105).
13. *A. wachsmuthi* WHITE, 1880 (=1).
14. **Agaricocrinus americanus* (ROEMER), 1852-1854.
15. *A. (Amphoracrinus) americanus* ROEMER, 1852-1854 (=14).
16. *A. gorbyi* MILLER, 1892 (=18).
17. *A. indianensis* MILLER, 1892 (=18).

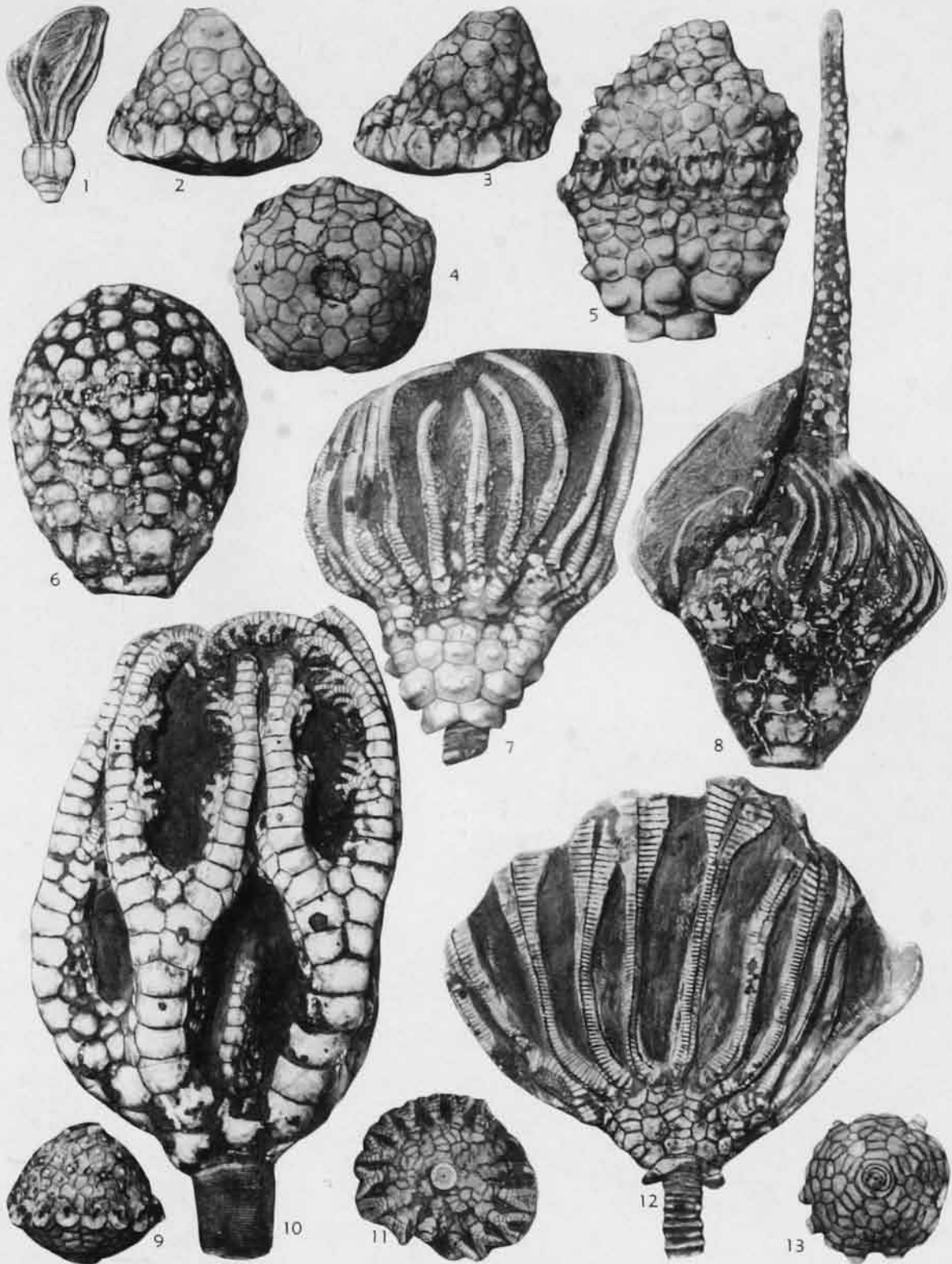
¹ Abbreviations or method of designating these plates are shown in parentheses; singular first followed by plurals.

18. **A. splendens* MILLER & GURLEY, 1890.
 19. **Alloprosalocrinus conicus* CASSEDAY & LYON, 1862.
 20. *A. gurleyi* MILLER, 1892 (=19).
 21. *A. tuberculatus* WOOD, 1909 (=19).
 22. *Amphoracrinus americanus* ROEMER, 1852-54 (=14).
 23. *Barycrinus angulatus* (MEEK & WORTHEN), 1860 (Crawfordsville specimens=24).
 24. **B. asteriscus* VAN SANT, n. sp.
 25. *B. herculeus* (MEEK & WORTHEN), 1868 (=26).
 26. **B. hoveyi* (HALL), 1861.
 27. *B. hoveyi* var. *herculeus* MEEK & WORTHEN, 1868 (=26).
 28. *B. lyoni* (HALL), 1861 (=123).
 29. **B. neglectus* MILLER & GURLEY, 1896.
 30. **B. princeps* MILLER & GURLEY, 1890.
 31. *B. stellatus* (HALL), 1858 (Crawfordsville specimens=24).
 32. *Batocrinus agnatus* MILLER, 1891 (=105).
 33. *B. commendabilis* MILLER & GURLEY, 1895 (=85).
 34. *B. crawfordsvillensis* MILLER, 1891 (=80).
 35. *B. decrepitus* MILLER, 1892 (=80).
 36. *B. grandis* (LYON & CASSEDAY), 1859 (=1).
 37. *B. jucundus* MILLER & GURLEY, 1890 (=105).
 38. *B. marinus* MILLER & GURLEY, 1890 (=171).
 39. *B. montgomeryensis* WORTHEN, 1884 (=84).
 40. *B. mundulus* (HALL), 1860 (=105).
 41. *B. subconicus* WORTHEN, 1884 (=84).
 42. *Calceocrinus bradleyi* MEEK & WORTHEN, 1869 (=96).
 43. **Camptocrinus crawfordsvillensis* SPRINGER, 1926.
 44. *C. planicirrus* (misspelling) BASSLER & MOODEY, 1943 (=45).
 45. **C. pleniccirrus* SPRINGER, 1926.
 46. *Catillocrinus bradleyi* MEEK & WORTHEN, 1868 (=86).
 47. *Conocrinites leae* TROOST, 1849 (=19).
 48. *C. tuberculatus* TROOST, 1849 (=19).
 49. **Corythocrinus fragilis* KIRK, 1946.
 50. **C. gracilis* KIRK, 1946.
 51. *Cosmetocrinus crawfordsvillensis* (MILLER & GURLEY), 1890 (=101).
 52. *C. indianensis* (MEEK & WORTHEN), 1865 (=101).
 53. **Cyathocrinites benedicti* (MILLER), 1892 (adv. pub. 1891).
 54. **C. insperatus* (LYON), 1869.
 55. **C. multibrachiatus* (LYON & CASSEDAY), 1859).
 56. **C. opimus* (MILLER & GURLEY), 1890.
 57. **C. poterium* MEEK & WORTHEN, 1870.
 58. *Cyathocrinus arboreus* MEEK & WORTHEN, 1865 (=55).
 59. *C. corrugatus* TROOST, 1849 (=26).
 60. *C. crawfordsvillensis* MILLER, 1882 (=121).
 61. *C. dekadactylus* LYON & CASSEDAY, 1860 (=97).
 62. *C. harrisi* MILLER, 1880 (=94).
 63. *C. hexadactylus* LYON & CASSEDAY, 1860 (=123).
 64. *C. hoveyi* HALL, 1861 (=26).
 65. *C. inspiratus* WACHSMUTH & SPRINGER, 1886 (=54).
 66. *C. lyoni* HALL, 1861 (=123).
 67. *C. multibrachiatus* var. *squarrosa* HALL, 1878 (=55).
 72. *C. tenibrachiatus* LYON, 1869 (=54).
 69. *C. tumidulus* MILLER & GURLEY, 1894 (=73).
 70. **Cybrocrinus concinnus* (MEEK & WORTHEN), 1870.
 71. **Decadocrinus depressus* (MEEK & WORTHEN), 1870.
 72. *D. grandis* WACHSMUTH & SPRINGER, 1897 (error pro 73).
 73. **D. tumidulus* (MILLER & GURLEY), 1894.
 74. *Dichocrinus (Camptocrinus) myelodactylus* WACHSMUTH & SPRINGER, 1897 (pl. 1, fig. 1=43).
 75. *D. expansus* MEEK & WORTHEN, 1868 (=119).
 76. **D. ficus* CASSEDAY & LYON, 1862.
 77. *D. polydactylus* CASSEDAY & LYON, 1862 (=119).
 78. **D. recurvibrachiatus* VAN SANT, n. sp.
 79. *D. stelliformis* MEEK & WORTHEN, 1868 (=119).
 80. **Dizygocrinus crawfordsvillensis* MILLER, 1891.
 81. **D. indianaensis* (LYON & CASSEDAY), 1860.
 82. *D. indianensis* (misspelling) WACHSMUTH & SPRINGER, 1897 (=81).
 83. *D. indianensis* var. *simplex* WACHSMUTH & SPRINGER, 1897 (=81).
 84. **D. montgomeryensis* WORTHEN, 1884.
 85. **Eretmocrinus commendabilis* (MILLER & GURLEY), 1895.

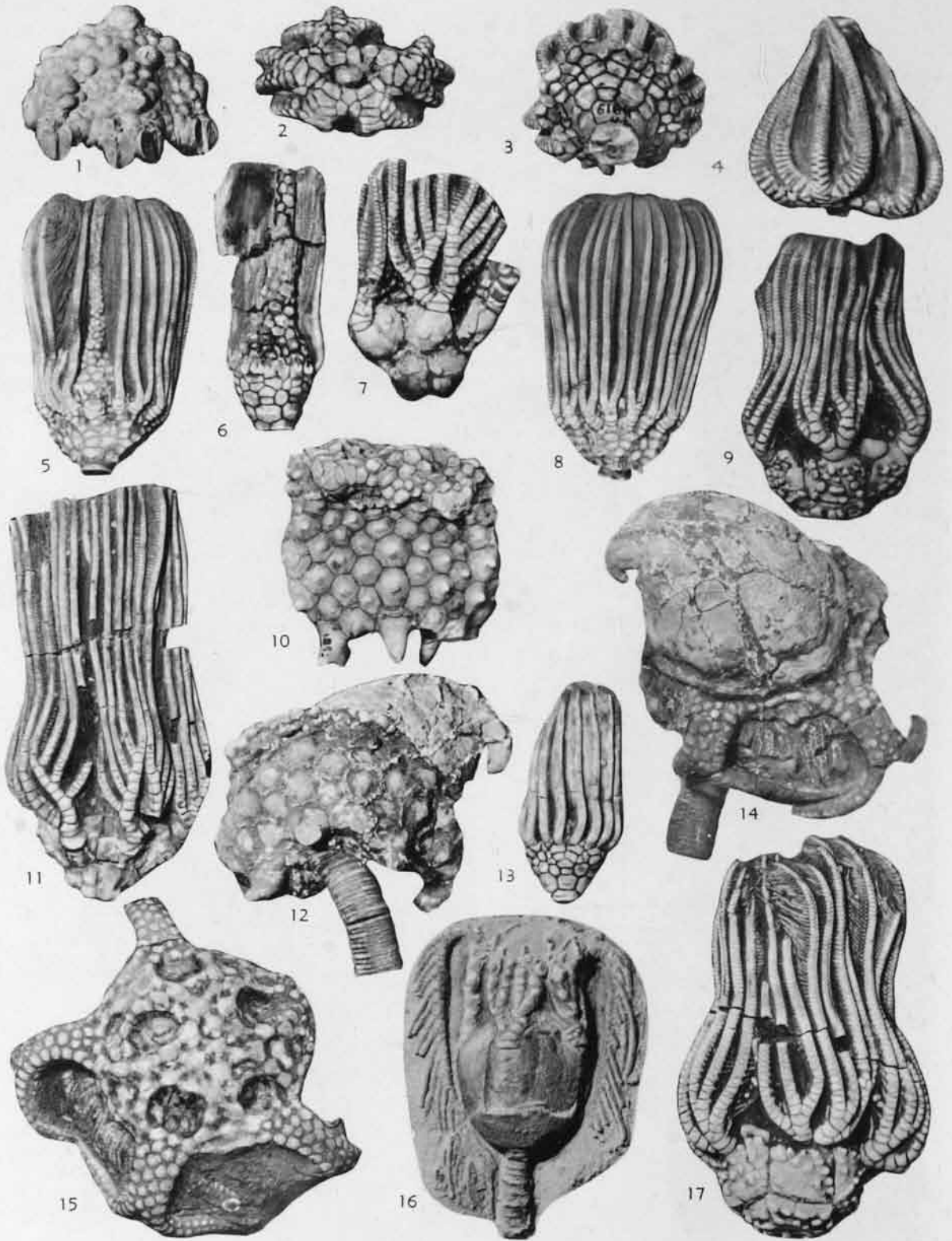
EXPLANATION OF PLATE 7

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE		PAGE
1.	122	<i>Dichocrinus</i> sp.; lateral view of crown identified by MILLER & GURLEY as <i>D. ficus</i> (UCWM 8942)	108
2-4.	110	<i>Alloprosalocrinus conicus</i> CASSEDAY & LYON; EA, E, and dorsal views of typical calyx (UCWM 8922)	9,11,13.
5-8.		<i>Abatocrinus grandis</i> (LYON & CASSEDAY); 5, EA view of large calyx showing details of ornamented surface (NYSM 11538); 6, C ray view of first crinoid calyx found at Crawfordsville (Horace Hovey, 1842); 7, A ray view of crown showing pairs of arms arising from single ambulacral openings at top of dorsal cup (WC 74); 8, A ray view of calyx showing long anal tube (UCWM 8925)	114
		<i>Dizygocrinus montgomeryensis</i> (WORTHEN); 9,11, B ray and dorsal views of holotype (IDG X68); 13, dorsal view of crown showing nature of proximal Brr (UCWM 8927)	100
		<i>Onychocrinus exculptus</i> LYON & CASSEDAY: CD view of typical crown (UCWM 8929C)	116
		<i>Eretmocrinus commendabilis</i> MILLER & GURLEY; D ray view of holotype showing well flattened distal parts of arms (UCWM 6475)	



VAN SANT & LANE—Crawfordsville Crinoids



VAN SANT & LANE—Crawfordsville Crinoids

86. **Eucatillocrinus bradleyi* (MEEK & WORTHEN), 1868.
 87. *Forbesiocrinus meeki* QUENSTEDT, 1885 (=166).
 88. *F. monroensis* MEEK & WORTHEN, 1861 (=107).
 89. *F. norwoodi* MEEK & WORTHEN, 1860 (=107).
 90. *F. ramulosus* LYON & CASSEDAY, 1859 (=111).
 91. *Gilbertocrinus (Goniasteroidocrinus) tuberosus* (LYON & CASSEDAY), 1859 (=92).
 92. **G. tuberosus* (LYON & CASSEDAY), 1859.
 93. *Goniasteroidocrinus tuberosus* LYON & CASSEDAY, 1859 (=92).
 94. **Goniocrinus harrisi* (MILLER), 1880.
 95. **Graphiocrinus mcadamsi* (MEEK & WORTHEN), 1873.
 96. **Halysiocrinus bradleyi* (MEEK & WORTHEN), 1869.
 97. **Histocrinus coreyi* (WORTHEN), 1875.
 98. *H. grandis* (WACHSMUTH & SPRINGER), 1879 (1880) (=97).
 99. **H. graphicus* (MILLER & GURLEY), 1890.
 100. **Hypselocrinus hoveyi* (WORTHEN), 1875.
 101. **H. indianensis* (MEEK & WORTHEN), 1865.
 102. *Lobocrinus spiniferus* WACHSMUTH & SPRINGER, 1897 (=171).
 103. *Macrocrinus jucundus* (MILLER & GURLEY), 1890 (=105).
 104. *M. lagunculus* (HALL), 1860 (=105).
 105. **M. mundulus* (HALL), 1860.
 106. *Ollacrinus tuberosus* (LYON & CASSEDAY), 1859 (=92).
 107. **Onychocrinus exculptus* LYON & CASSEDAY, 1860.
 108. *O. exculptus* WACHSMUTH & SPRINGER, 1879 (1880) (=107).
 109. *O. monroensis* (MEEK & WORTHEN), 1861 (=107).
 110. *O. norwoodi* (MEEK & WORTHEN), 1860 (=107).
 111. **O. ramulosus* (LYON & CASSEDAY), 1859.
 112. **Pachylocrinus aequalis* (HALL), 1861.
 113. *P. coreyi* (MEEK & WORTHEN), 1869 (=2).
 114. *P. disparilis* (MILLER & GURLEY), 1890 (=160).
 115. **P. gibsoni* (WHITE), 1878.
 116. *P. granuliferus* (MILLER & GURLEY), 1890 (=71).
 117. *P. gurleyi* (WHITE), 1878 (=112).
 118. *P. porrectus* (MILLER), 1892 (=162).
 119. **Paradichocrinus polydactylus* (CASSEDAY & LYON), 1862.
 120. **Parichthocrinus crawfordsvillensis* (MILLER & GURLEY), 1894.
 121. **Parisocrinus crawfordsvillensis* (MILLER), 1882.
 122. *P. subramosus* (MILLER & GURLEY), 1890 (=121).
 123. **Pellecrinus hexadactylus* (LYON & CASSEDAY), 1860.
 124. **Platycrinites hemisphericus* (MEEK & WORTHEN), 1865.
 125. *Poteroicrinites (Graphiocrinus; Scaphiocrinus) coreyi* MEEK & WORTHEN, 1869 (=2).
 126. *P. (Scaphiocrinus) coreyi* (MEEK & WORTHEN), 1869 (=2).
 127. *P. (Scaphiocrinus) mcadamsi* MEEK & WORTHEN, 1873 (=95).
 128. *P. (Zeacrinus?) concinnus* MEEK & WORTHEN, 1870 (=70).
 129. *Poteroicrinus circumtextus* MILLER & GURLEY, 1894 (=121).
 130. *P. coreyi* WORTHEN, 1875 (=97).
 131. *P. crawfordsvillensis* MILLER & GURLEY, 1890 (=101).
 132. *P. granilineus* MILLER & GURLEY, 1890 (=148).
 133. *P. hoveyi* WORTHEN, 1875 (=100).
 134. *P. indianensis* MEEK & WORTHEN, 1865 (=101).
 135. *P. magniventrus* SPRINGER, 1911 (=163).
 136. *P. (Pachylocrinus) concinnus* (MEEK & WORTHEN), 1870 (=70).
 137. *P. (Pachylocrinus) subaequalis* WACHSMUTH & SPRINGER, 1879 (1880) (=112).
 138. *P. (Scaphiocrinus) aequalis* (HALL), 1861 (=112).
 139. *P. (Scaphiocrinus) coreyi* (MEEK & WORTHEN), 1869 (=2).
 140. *P. (Scaphiocrinus) depressus* (MEEK & WORTHEN), 1870 (=71).
 141. *P. (Scaphiocrinus) gibsoni* (WHITE), 1878 (=115).
 142. *P. (Scaphiocrinus) gurleyi* (WHITE), 1878 (=112).
 143. *P. (Scaphiocrinus) unicus* (HALL), 1861 (=4).
 144. *P. (Scytalocrinus) grandis* WACHSMUTH & SPRINGER, 1879 (1880) (=97).
 145. *P. (Scytalocrinus) indianensis* (MEEK & WORTHEN), 1865 (=101).
 146. *P. (Scytalocrinus) robustus* (HALL), 1861 (=162).
 147. *P. subramosus* MILLER & GURLEY, 1890 (=121).
 148. **Sarocrinus granilineus* (MILLER & GURLEY), 1890.
 149. *Scaphiocrinus aequalis* HALL, 1861 (=112).
 150. *S. depressus* MEEK & WORTHEN, 1870 (=71).
 151. *S. disparilis* MILLER & GURLEY, 1890 (=160).

EXPLANATION OF PLATE 8

All figures are $\times 1$, specimens from Crawfordsville, Indiana, unless otherwise indicated.

FIGURE	PAGE
1. <i>Agaricocrinus americanus</i> (ROEMER); <i>A</i> ray view of typical calyx (UCWM 8121)	118
2,4. <i>Agaricocrinus splendens</i> MILLER & GURLEY, Indian Creek; dorsal and <i>D</i> ray views of holotype (UCWM 6256)	119
3. <i>Uperocrinus marinus</i> (MILLER & GURLEY); oblique dorsal <i>A</i> ray view of holotype (UCWM 6164)	118
5,8. <i>Dizygocrinus indianaensis</i> (LYON & CASSEDAY); crown from <i>C</i> side with arms removed to show part of tegmen and <i>E</i> ray view (UCWM 19198)	112
6,13. <i>Macrocrinus mundulus</i> (HALL); <i>C</i> ray views of specimens originally designed as syntypes of <i>Batocrinus jucundus</i> MILLER & GURLEY (UCWM 6259A, 6259B)	117
7,11. <i>Paradichocrinus polydactylus</i> (CASSEDAY & LYON);	
7, <i>A</i> ray view of incomplete crown (UCWM 8918A);	
11, <i>A</i> ray view of nearly complete crown (YPM 6447A)	124
9,17. <i>Platycrinites hemisphericus</i> (MEEK & WORTHEN); 9, <i>D</i> ray view of typical crown (UCWM 51853); 17, <i>A</i> ray view of larger specimen (UCWM 51852)	125
10,12,14,15. <i>Gilbertocrinus tuberosus</i> (LYON & CASSEDAY); 10,12, <i>A</i> ray and tegmental views, latter showing small delicate arms between tubular appendages of tegmen (IGS 1893); 14,15, lateral and oblique tegmental views showing attached shell of <i>Platyceras</i> , a coprophagous gastropod (UCWM 8920)	105
16. <i>Dichocrinus recurvibrachiatius</i> VAN SANT, n. sp.; lateral view of holotype (UCWM 51832), $\times 2$	121

152. *S. gibsoni* WHITE, 1878 (=115).
 153. *S. granuliferus* MILLER & GURLEY, 1890 (=71).
 154. *S. graphicus* MILLER & GURLEY, 1890 (=99).
 155. *S. gurleyi* WHITE, 1878 (=172).
 156. *S. lyoni* MILLER, 1894 (=2).
 157. *S. porrectus* MILLER, 1892 (=162).
 158. *S. robustus* HALL, 1861 (=162).
 159. *S. unicus* HALL, 1861 (=4).
 160. **Scytalocrinus disparilis* (MILLER & GURLEY), 1890.
 161. *S. hoveyi* (WORTHEN), 1875 (=100).
 162. **S. robustus* (HALL), 1861.
163. **Springericrinus magniventrus* (SPRINGER), 1911.
 164. **Synbathocrinus swallowi* HALL, 1858.
 165. *S. swallowi* BEEDE, 1906 (=164).
 166. **Taxocrinus colletti* (WHITE), 1880.
 167. *T. crawfordsvillensis* MILLER & GURLEY, 1894 (=120).
 168. *T. multibrachiatus* var. *colletti* WHITE, 1880 (=166).
 169. *T. norwoodi* MEEK & WORTHEN, 1860 (=107).
 170. *T. splendens* MILLER & GURLEY, 1896 (=166).
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